The Path from Fukushima:

Short and Medium-term Impacts of the Reactor Damage Caused by the Japan Earthquake and Tsunami on Japan's Electricity Systems

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Report Summary

This study reviews and updates the Nautilus Institute report After the Deluge: Short and Medium-term Impacts of the Reactor Damage Caused by the Japan Earthquake and Tsunami[1], which discussed the implications of the Sendai Earthquake on electricity supply and demand in the Tokyo Electric Power Company (TEPCO) and Tohoku Electric Power Company service areas. This report examines the difficulties that these two companies will likely face in meeting electricity demand in their service territories, given the available generating capacity of power stations both immediately and into the near and medium-term. It includes a scenario for providing some of the electrical energy and peak power needs in these service areas with "demand-side"—that is, energy efficiency savings and distributed generation that occur at customers' sites, as opposed to at central power stations—and renewable resources, including both consumer-sited and other renewable and non-renewable power generation. Finally, the report offers our appraisal of how these two power systems may evolve over the coming years, outlining best case, baseline case, and worst case scenarios.

Demand-side Approaches to Electricity Sector Rebuilding

For the purposes of this report, "demand-side" means energy generated or saved locally at the consumers' sites, rather than at a centralized power plant. An example would be an office building with a photovoltaic array on the roof that helps power the building. Excess energy from this array could potentially be distributed locally via a smart grid that can accept power inputs and distribute them at a local level. Alternatively, the lighting system in the building could be made more efficient thus, providing demand-side energy and power savings. Based on our analysis of the current and probable near-term future of the TEPCO/Tohuku electricity supply situation, Japan may wish to take this opportunity—albeit one both expected and unfortunate in its genesis—to examine carefully the costs of establishing a nationally integrated "smart grid". Such a grid would enable the use of intermittent renewable energy to be scaled up alongside an aggressive program promoting super-efficient end-use technologies, as well as energy conservation and peak power management at the end-use level. This approach may be cheaper, faster, environmentally cleaner, and more resilient in the short and the long-run than relying on largely coastal thermal and nuclear-fired power plants to make up for the immediate and long-term shortfalls in generating capacity. Our initial analysis of

[1] Prepared by Peter Hayes, David von Hippel, Richard Tanter, Takase Kae, Kang Jungmin, Wen Bo, Gordon Thompson, Yi Kiho, Arabella Imhoff, Scott Bruce and Joan Diamond, dated March 17, 2011, and available as http://www.nautilus.org/publications/essays/napsnet/reports/SRJapanReactors.pdf.

scenarios comparing approaches to address these shortfalls emphasizes, respectively "packages" of A) energy efficiency, renewable energy and distributed generation (EE/RE/DG), and B) central-station gas and nuclear plants. Our results suggest that while the former is more expensive in terms of capital costs, the annualized costs (that is, the annual costs of owning and operating the equipment—including, for example, high-efficiency appliances and other devices—and power plants included in the packages) of the two scenarios is similar enough ($11 versus $10 billion per year) that the more rapidly-deployed EE/RE/DG scenario easily becomes more cost-effective if the benefits of earlier recovery of otherwise unserved electricity demand in the affected areas are considered. The EE/RE/DG scenario of aggressive deployment, over the next four years, of energy-efficiency, renewable energy, and distributed (consumer-sited) gas-fired generation, is consistent with the work of Japan's Center for Low Carbon Society Strategy. The EE/RE/DG scenario provides, based on our initial estimate, the equivalent of 81 TWh of annual delivered electricity supplies to the citizens and businesses of the service territories after four years, and the equivalent of about 22 GW of delivered summer peak power. The EE/RE/DG scenario also results in 50% less CO_2 emissions than the central-station option, and thus contributes toward meeting Japan's ambitious greenhouse gas emissions reduction goals, as well as supporting the development of a "green economy" for Japan. Because the EE/RE/DG scenario starts to save and produce power almost immediately, whereas most of the elements of the central station alternative, even if fast-tracked, will take a minimum of two to three years to implement (and the other elements will take longer), the latter will incur economic costs due to the value of unmet demand. Taking this factor into account more than equalizes the cost of the EE/RE/DG scenario, estimated to be 14 cents/kWhe, with that of the central power station alternative, which is 12 cents before the cost of unmet demand is taken into account but much more afterward.

The need to rebuild a significant amount (estimated as high as$310 billion dollars, or over 25 trillion yen, according to recent news reports) of Japan's infrastructure provides an opportunity to construct new buildings, electricity supply grids, and factories with the most energy-efficient technologies in a manner that easily accommodates "smart grid" technologies. In so doing, the marginal costs of such improvements can be dramatically reduced, and much larger markets created for energy efficiency, distributed generation, and other demand-side management technologies, including technologies made in Japan.

The way that Japan's energy sector institutions, and the government agencies that oversee them, respond or are ultimately changed by the public's reaction to the earthquake, tsunami, and the Fukushima I accident will be crucial in determining whether Japan rapidly adopts a more aggressive posture toward energy efficiency and other demand-side and renewable resources, or whether it continues with a "business as usual" approach.

Existing and operable TEPCO and Tohoku centralized supply-side resources:

- Prior to the earthquake, TEPCO and Tohoku had a combined total of about 81,000 MW of supply-side resources, of which well over 7,000 MW were pumped-storage hydroelectric facilities used to store energy and provide peaking power;
- 7765 MW of thermal generating capacity on the TEPCO system was taken off line following the earthquake (of which 3665 MW of that capacity has since been restored as of April 9th, 2011). Thermal capacity on the Tohoku grid totaling 6146 MW was also damaged (of which 2750 MW of that capacity has since been restored as of April 9th, 2011), along with damage to transformer, transmission, and distribution facilities on the Tohoku grid;
- Under all but the most optimistic supply recovery/expansion scenarios, TEPCO and Tohoku will be unable to meet summer peak power demand in 2011 if peak demand is close to 2009/2010 levels.

Demand-side measures and resources for power companies affected:

- Both TEPCO and Tohoku initially announced power rationing programs, consisting of rolling blackouts in many areas, but exempting some regions, including earthquake-affected zones and central Tokyo. Power rationing in the TEPCO area has been much less extensive than expected, rationing in the Tohoku area has been thus far avoided, due to a combination of reduced business activity, loss of access to power supplies as a result of earthquake and tsunami damage to power plants and transmission and distribution infrastructure, and a massive and admirable effort of electricity conservation by the citizens of northern Honshu;
- Lack of generation capacity will spur TEPCO and other affected companies and their customers, to more aggressively pursue energy efficiency measures and generation of power on-site by consumers (or distributed generation) through the use of both renewable resources (such as solar PV, and solar hot water, which have the advantage of being largely coincident with peak summer power demand) or fossil resources (natural gas-fired units, for example).

Medium-term Implications for TEPCO and Tohoku Service Areas:

- The four affected Fukushima I reactors will not be reparable, and it may well be, given the explosion at Fukushima I unit 4, that a combination of damage and radioactive contamination at units 5 through 6 will render those units un-repairable as well;
- It is possible that other nuclear plants—a total of seven TEPCO, four Tohoku, and one Japan Atomic Power (the 1100 MW Tokai unit 2) nuclear reactor units, as well as a number of coal- and gas-fired plants, all of which went off-line following the earthquake—will also be affected, and be either un-repairable or require lengthy repairs;

- Absent implementation of demand-side resources on a massive scale, TEPCO and Tohoku will need to rely on existing fossil fuel plants much more heavily, probably for many years, than they would have needed to had they been able to use the nuclear plants.

We further analyze scenarios for how the TEPCO and Tohoku power systems will recover over the coming years. In our **Best Case** scenario, we find that about 4700 MW of nuclear generating capacity is gone, and must be replaced or otherwise compensated for by supply- or demand-side resources. Further, 2700 MW of new nuclear capacity that were to be developed at Fukushima I during the next decade seem highly unlikely to be completed, given the damage at the older units, and the generation that would have come from those units will need to be replaced or compensated for. An additional 6600 MW of nuclear capacity is likely to be offline for one to three years, 3300 MW at the Kashiwazaki-Kariwa plant is offline for inspection, and 4000 MW of thermal capacity seems likely to be offline through the summer. For the TEPCO service area, the annual output of the remaining operating nuclear units totals 4912 MW (this is the TEPCO nuclear capacity that was not affected by the earthquake and subsequent events). As a result, if demand in 2011 is similar to 2009 levels, TEPCO's thermal plants would be called upon to produce about 260 TWh of output in 2011, which implies that nearly all thermal plants must run nearly full-time. From the perspective of peak demand, the short-term situation is even more constrained. This implies that a combination of peak demand reduction measures, coupled with the decrease in electricity demand resulting from earthquake damage to infrastructure and the economy, will be required to get the TEPCO system through the next few years, even in this "Best Case" scenario.

In our **Base Case** scenario, we assume that nuclear plants (other than Fukushima I) in the earthquake-affected area will need to undergo more lengthy inspection, and/or inspections turn up problems that must be addressed, and/or local political opposition delays restarting the plants, and/or inspections at some thermal plants also turn up problems that mean that they are out of service longer, or need to be replaced. Here the supply shortfall for the two companies is likely to last longer, perhaps several years longer, and would need to be ameliorated by a combination of more thermal generation, construction of new thermal generation plants, and probably a significant effort to curb net demand for both electrical energy and peak power. Curbing demand could take the form of rotating power cuts, agreements with industry to curtail consumption at peak times (or, in fact, to move elsewhere, as unappealing as that is for the local economy), aggressive energy efficiency programs (which would have the added benefit of reducing fuel requirements and costs), and/or encouraging residents, businesses, and industries to develop on-site generation, including gas-fired combined heat and power systems and solar photovoltaic (PV) generation, which is particularly beneficial in meeting summer peak power demand..

In our **Worst Case** scenario, we assume that all of the nuclear power plants in the earthquake area are found to have significant seismic or other damage, leading to prolonged (more than 5 years) retrofit requirements, and some thermal plants are found to have been compromised to the point where they cannot be repaired and must be replaced (requiring several years). In addition, the results of inspections at the earthquake-affected power plants, coupled with nationwide public concern about the safety of nuclear plants, causes other nuclear plants (apart from the earthquake-affected plants) in the TEPCO/Tohoku service areas and maybe elsewhere in Japan to be taken off line on a rotating basis for damage assessment and/or earthquake retrofit. These additional conditions would likely result in the need for many more new thermal plants (and related fuel supplies) and an even higher reliance on demand-side measures (including power rationing) than in the base case if the country is to balance available supply and demand over five to ten years.

Although we have labored hard to produce an accurate accounting of the impact of this disaster on Japan and the region, we recognize that data and analysis produced this quickly is inevitably error-prone. Naturally, we request readers to notify us of any such errors.
We continue to offer our heartfelt condolences go to the Japanese people who are suffering from this combined natural and technological disaster and have commenced recovery with amazing calm and courage in the face of such calamity.

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1. Introduction

This study reviews and revises the Nautilus Institute report After the Deluge: Short and Medium-term Impacts of the Reactor Damage Caused by the Japan Earthquake and Tsunami[2] which discussed the implications of the Sendai Earthquake on electricity supply and demand in the Tokyo Electric Power Company (TEPCO) and Tohoku Electric Power Company service areas. In Section 2 we examine the difficulties that these two companies will likely face in meeting electricity demand in their service territories, accounting for the status of nuclear and non-nuclear power stations that generate electric power in these systems both immediately and into the near and medium-term, given the abrupt temporary, and in some cases, effectively permanent, loss of generation capacity. Section 2 also includes a scenario for providing some of the electrical energy and peak power needs in these service areas with "demand-side" , that is, energy efficiency and distributed generation that occurs at customers' sites, as opposed to in central power stations, and renewable resources, including both consumer-sited and other renewable and non-renewable generation. Section 3 offers our appraisal of how these two power systems may evolve over the coming years, outlining best case, baseline case, and worst case scenarios. This updated version was completed late on April 10, Tokyo time.

2. Implications of damage to nuclear reactors and other power plants for the North Honshu electricity system

Power Requirements on the TEPCO and Tohoku Electric Power Company Systems

The earthquake affected the TEPCO and Tohoku Electric Power Company (Tohoku) systems, which together serve the northern part of the Island of Honshu. As shown in Figure 1[3] Tohoku serves the portion of Honshu north of about 37° N latitude, with TEPCO serving the consumers located approximately south of 37° N latitude and east of 138° E longitude. TEPCO serves nearly 45 million people, about 35 percent of Japan's population. Another 12 million people, over 9 percent of Japan's population, are served by Tohoku.

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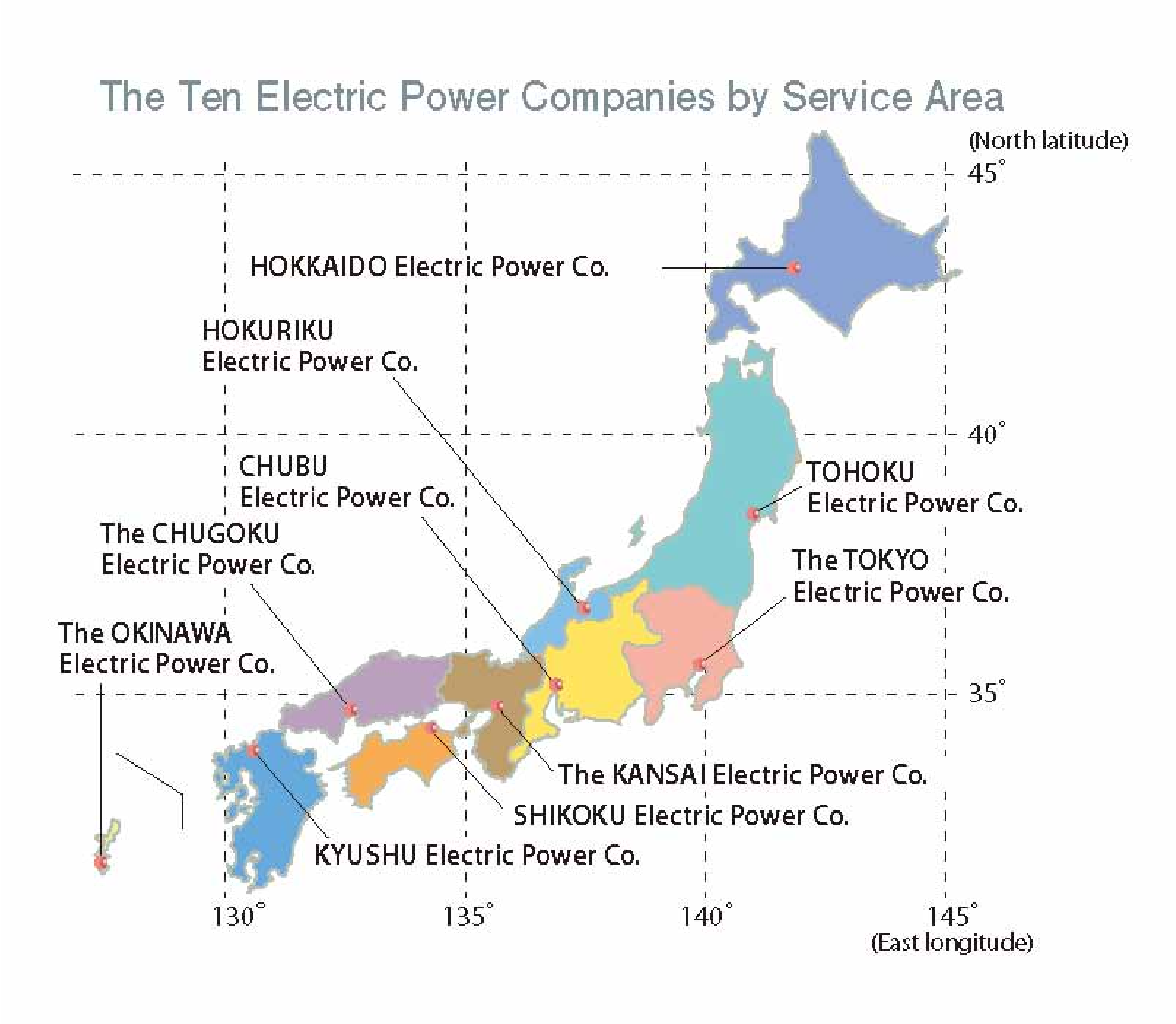
[2] Prepared by Peter Hayes, David von Hippel, Richard Tanter, Takase Kae, Kang Jungmin, Wen Bo, Gordon Thompson, Yi Kiho, Arabella Imhoff, Scott Bruce and Joan Diamond, dated March 17, 2011, and available as http://www.nautilus.org/publications/essays/napsnet/reports/SRJapanReactors.pdf.

[3] From Federation of Electric Power Companies of Japan (FEPC) website: <http://www.fepc.or.jp/english/energy_electricity/company_structure/sw_index_01/index.html, visited 3/16/2011>.

Figure 1: Japanese power companies



In 2009, TEPCO's sales to its customers totaled about 280 terawatt hours (TWh, or billion kilowatt-hours). Just over a third of these sales (34.3 percent) were to residential ("lighting") customers, with about 28 percent to industrial customers, and the remainder (about 38 percent) to commercial consumers. TEPCO's sales have changed very little, on a net basis, during the past five years, with 2009 sales about two percent less than in 2004. Figure 2 shows trends in TEPCO sales and in peak power demand from 2000 through 2009[4]. Key industrial subsectors in the TEPCO service territory

[4] In Figure 2 (from TEPCO website, http://www.tepco.co.jp/ir/data/hanbai-j.html) the red line and figures in red text show peak demand in units of 10,000 kW. The bars show annual energy demand by major consumer group, in units of 100 million kWh, with the dark blue bars representing the residential sector and the sum of the grey and light blue bars representing the commercial and industrial sectors.

include the Machinery, Chemicals, Steel, Railway, Other Manufacturing, and "Others" sector, as shown in Figure 3.

Figure 2: Trends in Energy and Peak Power Demand in the TEPCO Service Area (GWh)

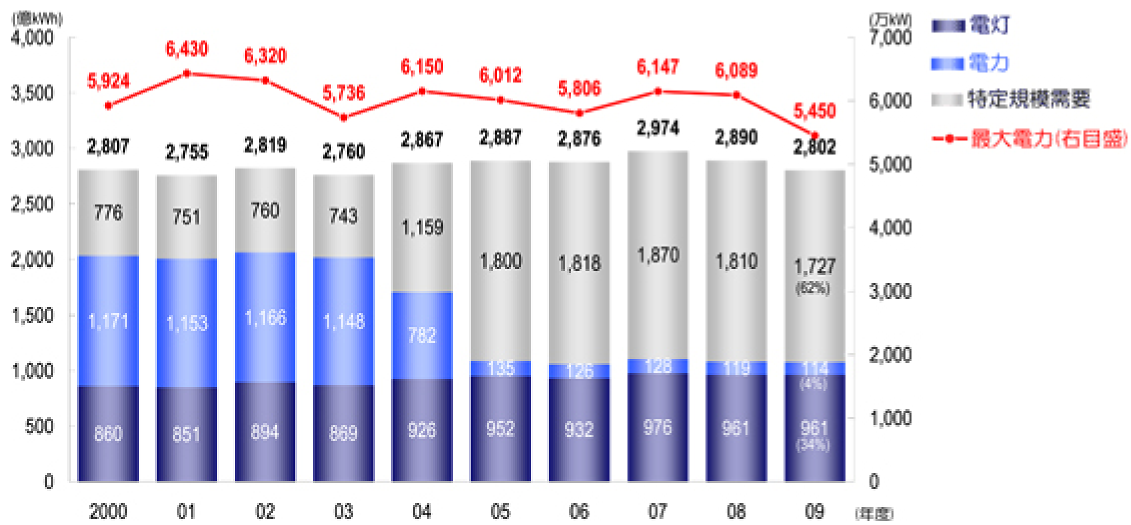
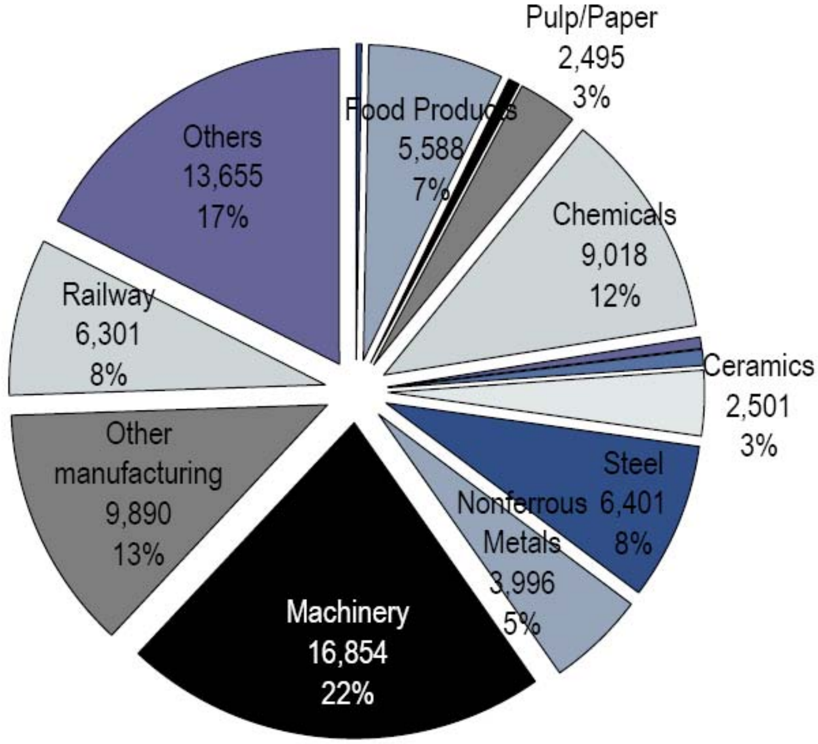


Figure 3: Industrial Energy Use by Subsector, TEPCO Service Territory, FY2009 (GWh) [5]



Tohoku sales in 2010 totaled about 79 TWh[6]. Tohoku sales in 2009 were about the same as in 2010, and in fact sales overall grew at an average of only 0.65 percent annually from 2000 through 2009. Electric energy demand in the Tohoku service territory is split almost evenly between the residential, commercial, and industrial sectors, with the commercial sector constituting about 36 percent of demand, and the residential and industrial sectors each contributing about 32 percent (see Figure 4). The machinery and metals subsector accounts for by far the largest portion of Tohoku's industrial energy demand, with non-ferrous metals, steel, chemicals, and non-specified industries also major consumers (see Figure 5).

[5] Figure 3 from T, Miyazaki, Citi Financial, "Eastern Japan earthquake/Power supply, Update 2: Can "super Cool Biz", residential cuts, and alternative energy fill the gap?, Available as https://ir.citi.com/OFkjEuk%2FDT892tjVJ62oaDtY1oNg7R7YZTwyuMCrMeY%3D.

[6]Tohoku Electric Power Company, "Annual Report 2010." Available as < http://www.tohoku-epco.co.jp/ir/report/pdf/ar2010.pdf>.

Figure 4: Energy Demand by Sector in the Tohoku Service Territory, FY2009 (GWh)

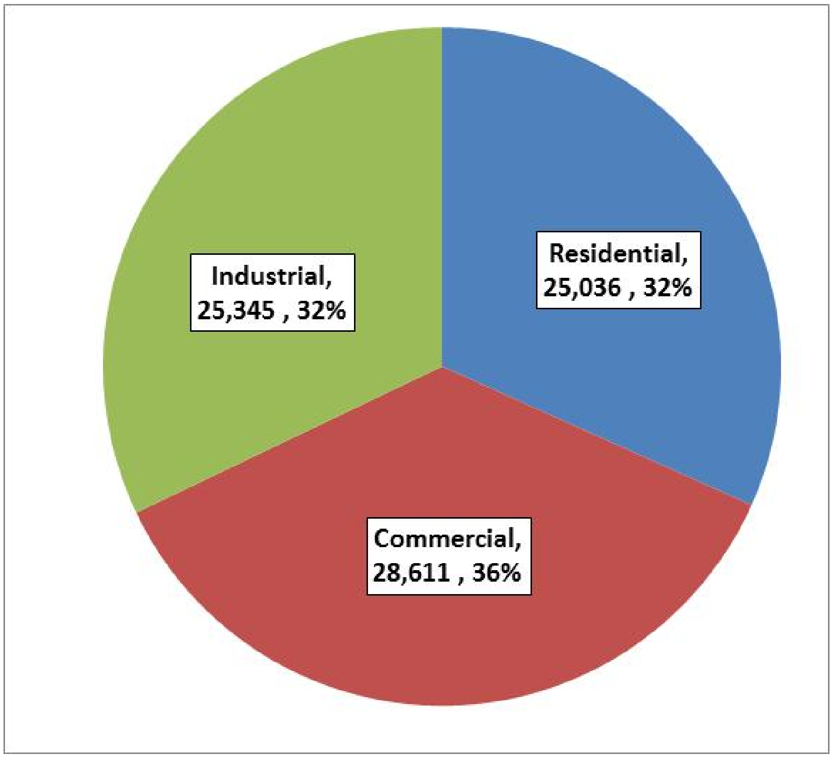
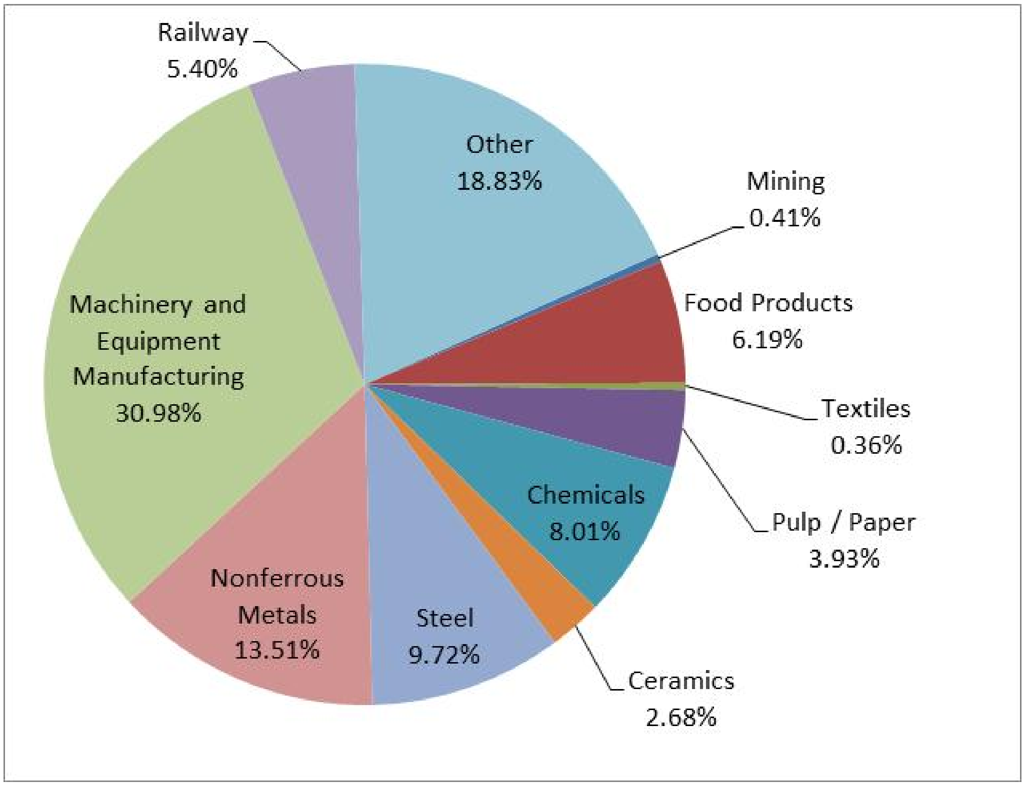


Figure 5: Industrial Energy Demand by Subsector in the Tohoku Service Territory, FY2009 (GWh)



TEPCO's generating plants produced just over 300 terawatt hours in 2009, about 30 percent of which was by nuclear plants.[7] In 2009 Tohoku's generation and net power purchases totaled about 87 TWh, with about 23 percent of this total from nuclear power.[8] These levels of generation and purchased power consumption correspond to average power requirements over a year of 34,000 MW and 9,900 MW for TEPCO and Tohoku, respectively. TEPCO's peak power demand in 2009 was about 55,000 MW, with a three-peak-day average of about 52,000 MW, and Tohoku's 2010 peak was about 14,500 MW. Based on recent news reports in Japan TEPCO expected that its peak power demand in the days immediately following the earthquake (not including the impacts of electricity rationing) would be 41,000 MW.[9] Below we compare generation available in the short term in each service area with expected peak demand and estimated energy needs.

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[7]Tokyo Electric Power Company, "Annual Report 2010," available as http://www.tepco.co.jp/en/corpinfo/ir/tool/annual/pdf/ar2010-e.pdf.

[8]Tohoku Electric Power Co., Inc. "FACTBOOK," 2010, http://www.tohoku-epco.co.jp/ir/fact-e.htm.

[9] This peak demand was apparently "..estimated on the basis of the actual demand recorded in March of last year and the presumed impact of the recent earthquake." Ministry of Economy, Trade and Industry, Outlook for Future Electricity Demand and Supply under TEPCO Jurisdiction and Actions being Taken, dated March

Existing and Operable TEPCO and Tohoku Supply-side Resources

Prior to the earthquake, TEPCO and Tohoku had a total of about 81,000 MW of supply-side resources to draw upon (16,650 for Tohoku as of 2009, and about 64,500 for TEPCO), of which at least 7,314 MW were pumped-storage hydroelectric facilities used to store energy and provide peaking power.[10] Table 1 provides a listing of most of the power plants in the two utility areas, but excludes purchased power and several smaller thermal power plants. A number of nuclear and thermal (fossil-fueled) power plants were taken off-line as a result of the earthquake, and of those, the Fukushima I units are likely to be off-line indefinitely, if not permanently. Although a full description of the damage to the nuclear power units due to the earthquake and subsequent events is beyond the scope of this report, the Attachment provided at the end provides a brief description of the impacts of the earthquake on the nuclear units in the TEPCO and Tohoku service territories. A more complete description of those impacts through March 17 is also available in our original Report (see footnote 1).

7765 MW of thermal generating capacity on the TEPCO system was taken off line following the earthquake. 4165 MW of that capacity has since been restored (by April 9th, 2011).[11] A roster of the TEPCO plants affected by the earthquake or otherwise off-line includes:

- One of the 265 MW Goi LNG-fired units is under periodic maintenance, and expected to be in operation by the end of April;
- A 600 MW LNG-fired unit at Sodegaura is likewise under maintenance, and expected to be in operation by the end of April;
- Six units at Yokosuka (units #3, #4, #7, #8, crude oil and fuel oil fired, and two gas turbine units #1, #2, fired by municipal gas and diesel) have been retired for the long-term (but not yet fully decommissioned) since April, 2010 due to the slowing growth in electricity demand, growing concerns about global warming (these units are relatively inefficient), and the recovery of the Kashiwazaki-Kariwa nuclear power plants from the Earthquake in 2007. It

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25, 2011, and available as <http://www.meti.go.jp/english/electricity_supply/pdf/20110325_electricity_prospect.pdf>.

10 TEPCO has about 2000 MW of total hydroelectric capacity distributed among 209 smaller units, but it is unclear to us what fraction of these units, if any, are of the pumped-storage type.

11 Includes the full 1000 MW of unit #5 of the Kasima oil-fired plant, which was apparently restarted at 50% capacity on April 8th (see, for example, "Tepco to restart two quake-hit oil-fired Kashima units Fri", Platts, dated 7 April 2011, available as http://www.platts.com/RSSFeedDetailedNews/RSSFeed/ElectricPower/8761689.

is expected that units #3 (350MW), #4 (350MW) and the two gas turbines (144 MW) will be restarted around July, 2011, but that decommissioning of the other units will continue[12];

- One of the two 1000 MW Higashi Ogijima LNG-fired plants was taken off line by the earthquake, and sustained minor damage, but was restarted on March 24th, 2011[13];
- Two 600 MW and two 1000 MW crude oil and fuel oil-fired units at Kashima were taken off line after the earthquake, but all have been restarted as of April 8th or are expected to restart by the end of April, 2011;
- One 600 MW and one 1000 MW crude oil and fuel oil-fired unit at Hirono were taken off line after the earthquake, but are expected to be restarted after the summer of 2011, as is a 1000 MW coal-fired unit at Hitachinaka;
- As noted above, all of the Fukushima I and II nuclear units were taken off line, and some heavily damaged, by the earthquake and subsequent events;
- Three 1100 MW units at the Kashiwazaki-Kariwa plant are off-line since the earthquake in 2007. TEPCO is willing to restart units #2 to #4, but it is unclear to us when they might be restarted due to the expected local opposition.
- Most of TEPCO's pumped hydro generation was taken off line during the earthquake, but has since been restored. Table 2 summarizes the capacity and status of TEPCO generation resources.

[12] Source: Yokosuka Keizai Shinbun (28/03/2011), available as http://yokosuka.keizai.biz/headline/533/>.
[13] Source: TEPCO press release, available as http://www.tepco.co.jp/cc/press/11032402-j.html>

Table 1: Power Plants in the TEPCO and Tohoku Service Areas[14]

Energy Source	Name of Plant or Type	Unit Number	Company	Installed Capacity (MW)	Type of Reactor** or Fuel	Start Date (Year/Month)
Nuclear	Higashi-Dori	1	Tohoku	1,100	BWR	2005.12
		1		524	BWR	1984.6
Nuclear	Onagawa	2	Tohoku	825	BWR	1995.7
		3		825	BWR	2002.1
		1		460	BWR	1971.3
		2		784	BWR	1974.7
Nuclear	Fukushima Daiichi	3	TEPCO	784	BWR	1976.3
		4		784	BWR	1978.1
		5		784	BWR	1978.4
		6		1,100	BWR	1979.1
		1		1,100	BWR	1982.4
Nuclear	Fukushima Daini	2	TEPCO	1,100	BWR	1984.2
		3		1,100	BWR	1985.6
		4		1,100	BWR	1987.8
		1		1,100	BWR	1985.9
		2		1,100	BWR	1990.9
		3		1,100	BWR	1993.8
Nuclear	Kashiwazaki Kariwa	4	TEPCO	1,100	BWR	1994.8
		5		1,100	BWR	1990.4
		6		1,356	ABWR	1996.11
		7		1,356	ABWR	1997.7
Tokai		2		1,100	BWR	1978.11
TOTAL NUCLEAR				**20,582**		
Hydro	Pumped-storage (total)		TEPCO	6,808		
Hydro	Shinanogawa		TEPCO	177		
Hydro	Pumped-storage (total)		Tohoku	460		
Hydro	Pumped-storage (total)		EPDC*	3,275		
Hydro	Other		EPDC*	1,132		
TOTAL PUMPED-STORAGE HYDRO				**10,543**		
TOTAL OTHER HYDRO				**1,309**		
Thermal	Higashi Niigata		Tohoku	4,600	LNG, other Gas	
Thermal	Haramachi		Tohoku	2,000		
Thermal	Noshio		Tohoku	1,300	Coal	
Thermal	Akita		Tohoku	1,300	Crude, Fuel Oil	
Thermal	Futtsu		TEPCO	4.534	LNG	
Thermal	Kashima		TEPCO	4,400	Crude, Fuel Oil	
Thermal	Hirono		TEPCO	3,800	Crude, Fuel Oil, Coal	
Thermal	Sodegaura		TEPCO	3,600	LNG	
Thermal	Anegasaki		TEPCO	3,600	Crude, Fuel Oil, LNG, LPG, NGL	
Thermal	Yokohama		TEPCO	3,325	Crude, Fuel Oil, LNG, NGL	
Thermal	Chiba		TEPCO	2,880	LNG	
Thermal	Yokosuka		TEPCO	2,274	Crude, Fuel Oil, other Gas, Diesel Oil	
Thermal	Higashi Ogishima		TEPCO	2,000	LNG	
Thermal	Goi		TEPCO	1,886	LNG	
Thermal	Kawasaki		TEPCO	1,500	LNG	
Thermal	Minami Yokohama		TEPCO	1,150	LNG	
Thermal	Shinagawa		TEPCO	1,140	LNG	
Thermal	Ohi		TEPCO	1,050	Crude	
Thermal	Hitachinaka		TEPCO	1,000	Coal	
TOTAL THERMAL				**42,810**		
Renewable	Hachijo-jima		TEPCO	0.5	Wind	
Renewable	Hachijo-jima		TEPCO	3.5	Geothermal	
Renewable	(Five Units at Four Sites)		Tohoku	243.8	Geothermal	
Renewable	Other		Tohoku	16.2	Total of other non-hydro renewable	
TOTAL NON-HYDRO RENEWABLE				**264**		
TOTAL ALL GENERATION				**75,508**		
TOTAL ALL GENERATION LESS PUMPED-STORAGE				**64,965**		

*Plants owned by EPDC (Electric Power Development Co., LTD.) but in the TEPCO or Tohoku service territories

** BWR - Boiling Water Reactor, ABWR = Advanced Boiling Water Reactor, LNG = Liquefied Natural Gas, NGL = Natural Gas Liquids, LPG = Liquefied Petroleum Gas.

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[14]Sources: Federation of Electric Power Companies of Japan, http://www.fepc.or.jp/english/energy_electricity/location/thermal/index.html and similar, visited 3/16/2011. Some data from Tokyo Electric Power Company, "Annual Report 2010," available as http://www.tepco.co.jp/en/corpinfo/ir/tool/annual/pdf/ar2010-e.pdf. and Tohoku Electric Power Co., Inc. "FACTBOOK," 2010, http://www.tohoku-epco.co.jp/ir/fact-e.htm.

Table 2: Summary of Power Plants Capacity and Status in the TEPCO Service Territory

Power Plant Type	MW
Hydro--Pumped Storage*	7903
Hydro--Non-pumped Storage*	1095
Thermal--pre earthquake capacity	37556
Thermal--Taken off-line due to Earthquake	7765
Thermal--Capacity Taken off-line but Restored as of 4/9/11	4165
Thermal--undergoing periodic maintenance as of 4/9/11	1600
Thermal--available current capacity as of 4/9/11^	32356
Nuclear--total pre-earthquake capacity**	18408
Nuclear--off-line due to earthquake**	7528
Nuclear--under periodic maintenance	5968
Nuclear--available current capacity	4912

*Estimate assuming that half of the less than 2000 MW of smaller TEPCO hydro plants are also of the pumped-storage type. (Specific data unavailable as of this writing.)
^ Excludes units 5 through 8 (1400 MW total) of the 2274 MW Yokosuka plant, which have been retired and are apparenty being decommissioned.
**Includes Japan Atomic Power Co. Tokai Nuclear plant, which sells power to both TEPCO and Tohoku.

In the Tohoku service territory, thermal power plants at Haramachi (totaling 2000 MW of capacity) are apparently heavily damaged, due to flooding and equipment damage, and may take six months or more to bring back on line. The newer Sendai thermal power plant unit 4 (446 MW) suffered flooding, as did the 950 MW Shin-Sendai thermal plant, which was evacuated due to a fire at the nearby oil refinery. Damage to transformer, transmission, and distribution facilities on the Tohoku grid occurred as well. Table 3 provides a summary of the capacity and status of the major power plants for the Tohoku service territory.

Table 3: Major Power Plants in the Tohoku Service Territory and Current Status (as of 4/9/2011)

Name of Plant	Unit	MW	Type/Fuels	Status/Notes
Daini Numazawa		460	Hydro/Pumped Storage	
Other Pumped Storage		46	Hydro/Pumped Storage	
Others		2374	Hydro	209 small plants
Higashi Niigata	Total	4600	Thermal: LNG, other Gas	
	#1 (Minato)	350	Fuel Oil,LNG	Retired due to age
	#2 (Minato)	350	Fuel Oil,LNG	
	#1	600	Crude, Fuel Oil, Natural Gas, LNG	
	#2	600	Crude, Fuel Oil, Natural Gas, LNG	
	#3	1090	LNG	Combined cycle type
	#4	1610	LNG	Combined cycle type
Haramachi	Total	2000	Thermal: Coal	
	#1	1000	Coal	Off-line due to earthquake (fire)
	#2	1000	Coal	Off-line due to earthquake (fire)
Akita	Total	1300	Thermal: Oil	
	#2	350	--Crude and Fuel Oil	
	#3	350	--Crude and Fuel Oil	
	#4	600	--Crude and Fuel Oil	
Noshiro	Total	1200	Thermal: Coal	
	#1	600	--Coal	Taken off line due to earthquake, since restarted
	#2	600	--Coal	Taken off line due to earthquake, since restarted
Hachinohe	#3	250	Thermal: Crude and Fuel Oil	Off-line due to EQ, restarted 3/20/2011
Shin-Sendai				
	#1	350	Thermal: Crude and Fuel Oil	Off-line due to earthquake
	#2	600	Thermal: Crude and Fuel Oil, Natural Gas	Off-line due to earthquake
Nigata	#4	250	Thermal: Gas, Fuel Oil	
	#5	109	Thermal: Natural Gas	Combined cycle: Will start July 2011
Sendai	#4	446	Thermal: Natural Gas	Off-line due to earthquake
Onagawa	#1	524	Nuclear: BWR	Off-line due to earthquake
	#2	825	Nuclear: BWR	Off-line due to earthquake
	#3	925	Nuclear: BWR	Off-line due to earthquake
Higashidori	#1	1100	Nuclear: BWR	Under inspection until the end of June
Kuzuneda	#1	50	Geothermal	
	#2	30	Geothermal	
Uenotai	#1	28.8	Geothermal	Off-line due to earthquake
Sumikawa	#1	50	Geothermal	
Yanagizu-Nishiyama	#1	65	Geothermal	

Figure 6 compares the available generation in the TEPCO service territory with expected peak power demand under several different possible generation availability scenarios. Here the "Summer" case assumes that the four Kashiwazaki-Kariwa plants now operating continue to do so through the summer, along with all of the thermal units that have been off-line except the Hirono units[15]. In addition, this case includes 400 MW of new thermal plant construction (gas turbines) that are reportedly to be completed by early summer. We assume that this 400 MW includes the 244 MW of gas combustion turbines being shipped to TEPCO by the Thai utility EGAT (see below). The "Summer (optimistic)" case assumes the same generation line-up is available by the time of the

[15] TEPCO plans to restart the 1000 MW Hitachinaka coal-fired plant as of mid-July. TEPCO, Press Release (Mar 25, 2011), Power Supply and Demand Outlook in This Summer and Measures. Available as http://www.tepco.co.jp/en/press/corp-com/release/11032510-e.html>

summer peak, but that the expected peak itself is 10 percent lower than the 55 GW (about the same as 2009 peak) assumed by TEPCO and in our "Summer" case.[16] The "Summer (Best Case)" variant meets a peak demand of 52 GW, about the same as the three-day average peak in 2009, but assumes that the three Kashiwazaki-Kariwa nuclear units that are under inspection are back on line by summer, and the thermal units are available as in the "Summer (optimistic)" case. In each case, it is assumed that all of the generation available is available at the time of peak demand, including all of the pumped-storage hydro capacity. Given that assumption, TEPCO generation would not be sufficient to meet peak demand in the "Summer" case, but would barely meet and meet, respectively, peak power requirements in the "Summer (optimistic)" and "Summer (Best Case)" options. Under real circumstances, it is unlikely that all generators would be available at full capacity at the time of the peak, which means that either the generation will be insufficient, or demand will need to be lowered. From an annual energy output standpoint, if the TEPCO units that are operating in the "Summer" case are able to maintain approximately the average capacity factors they reached before the earthquake (about 80 percent for nuclear units, 65 percent for thermal units, and an assumed 50 percent for the approximately 10 percent of TEPCO's hydroelectric capacity that is not pumped-storage hydro units), then the remaining TEPCO generators will come about 17 percent short of meeting annual electricity requirements (including transmission losses), if requirements are about the same level as 2009 sales.

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[16] TEPCO News, "Press Release (Mar 25,2011), Power Supply and Demand Outlook in This Summer and Measures", available as http://www.tepco.co.jp/en/press/corp-com/release/11032510-e.html,

Figure 6: Comparison of TEPCO Available Capacity and Peak Demand During Summer, 2011 (MW)

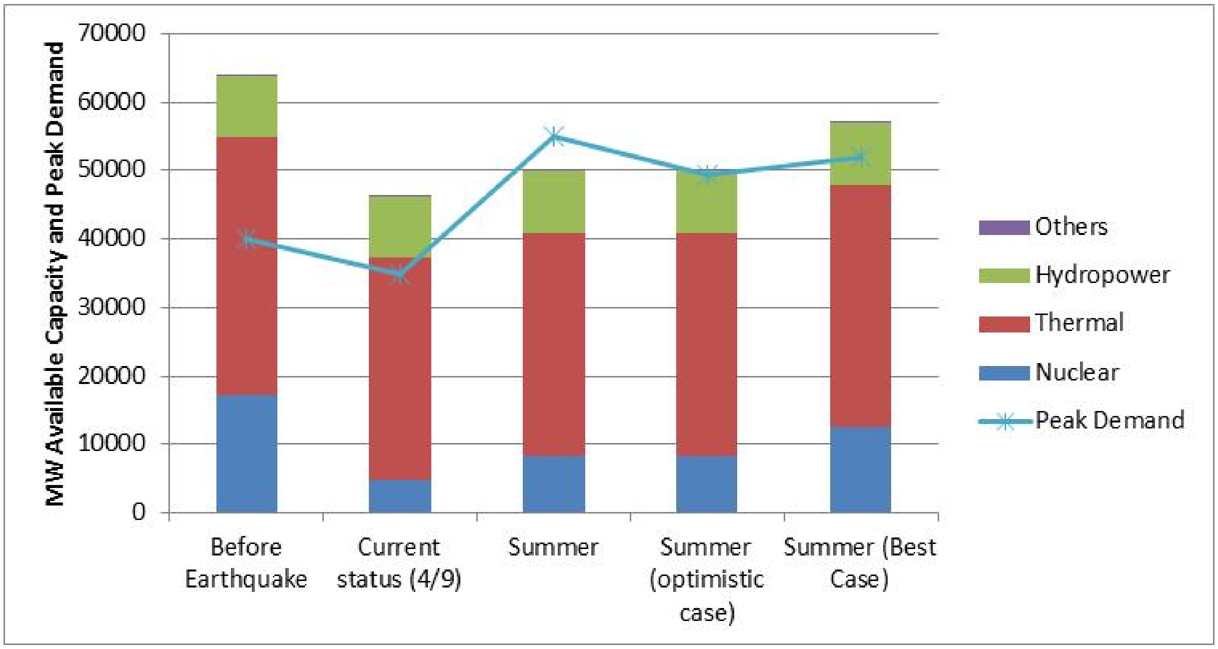
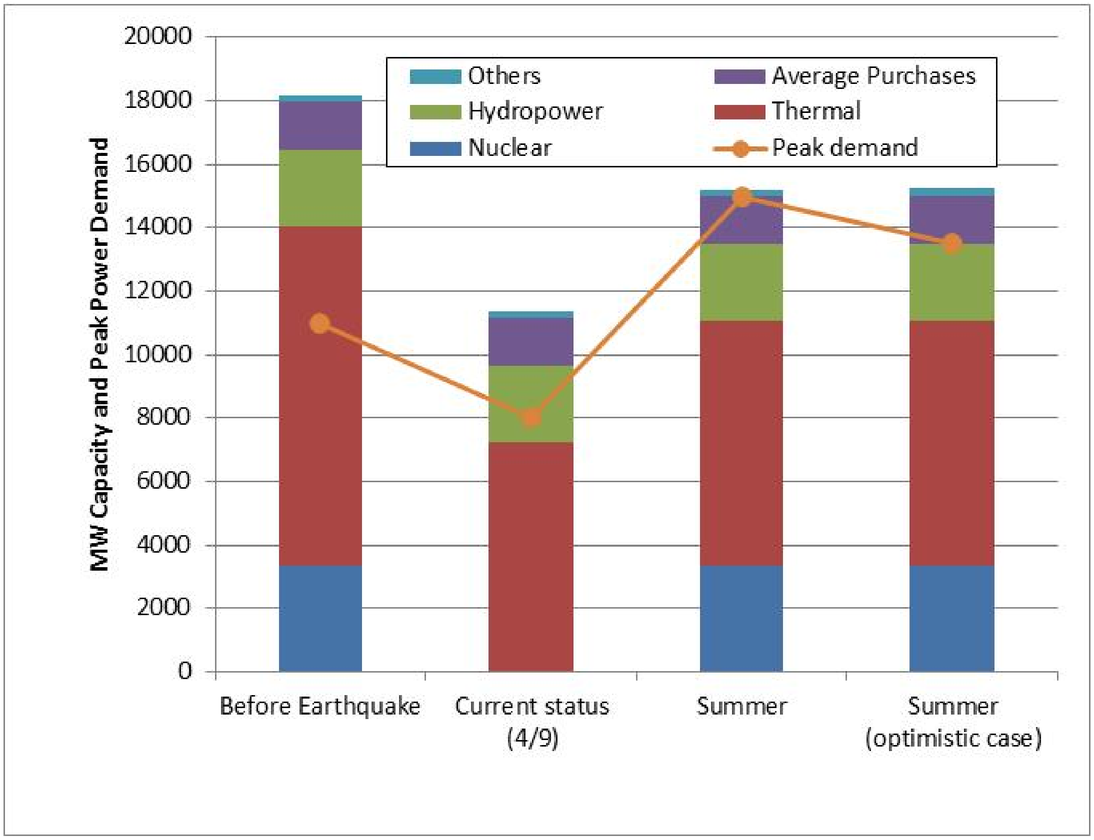


Figure 7 compares the level of recorded and expected power demand in the Tohoku service territory with the total available capacity before the earthquake, just after the earthquake (at the time of this writing), and this summer in a base and "optimistic" case where slightly more geothermal generation capacity is available, and peak demand is 10 percent lower. This figure shows that even if all operable capacity, including power available for purchase, in the Tohoku service territory were in fact available at the time of peak power needs, it would be just barely enough to cover peak demand. From an annual energy output standpoint, if the Tohoku units that are still operating are able to maintain approximately the average capacity factors they reached before the earthquake (about 70 percent for nuclear units, 65 percent for thermal units, 60 percent for geothermal units, and 50 percent for non-pumped-storage hydro units), and if power is available for purchase at the same level as in 2009, then the remaining Tohoku generators will be able to just meet annual electricity requirements at about the same level as 2009 or 2010 sales, including transmission losses.

Figure 7: Comparison of Tohoku Available Capacity and Peak Demand During Summer, 2011 (MW)



Japan uses two electric power systems of two different frequencies. TEPCO, Tohoku, and utilities to the north generate and use power at a frequency of 50 Hz (Hertz, or cycles per second), while other Japanese utilities generate and distribute 60 Hz power. The two systems are tied together through three frequency inverter stations, as shown in Figure 8, but the net result is that without the addition of more converter stations and transmission facilities, the capacity of TEPCO and Tohoku to import power from other big systems is limited, apparently to about 1000 MW.[17] This means that the big electricity systems in the southern part of Honshu Island can only provide a very limited amount of support to the TEPCO and Tohoku service territories, even if the southern systems had significant spare capacity. The electricity system on Hokkaido is small relative to the TEPCO and Tohoku systems, and the undersea DC (direct current) cable that connects Hokkaido to Honshu is of very limited capacity, so again, cannot help the TEPCO/Tohoku systems much in the short term.

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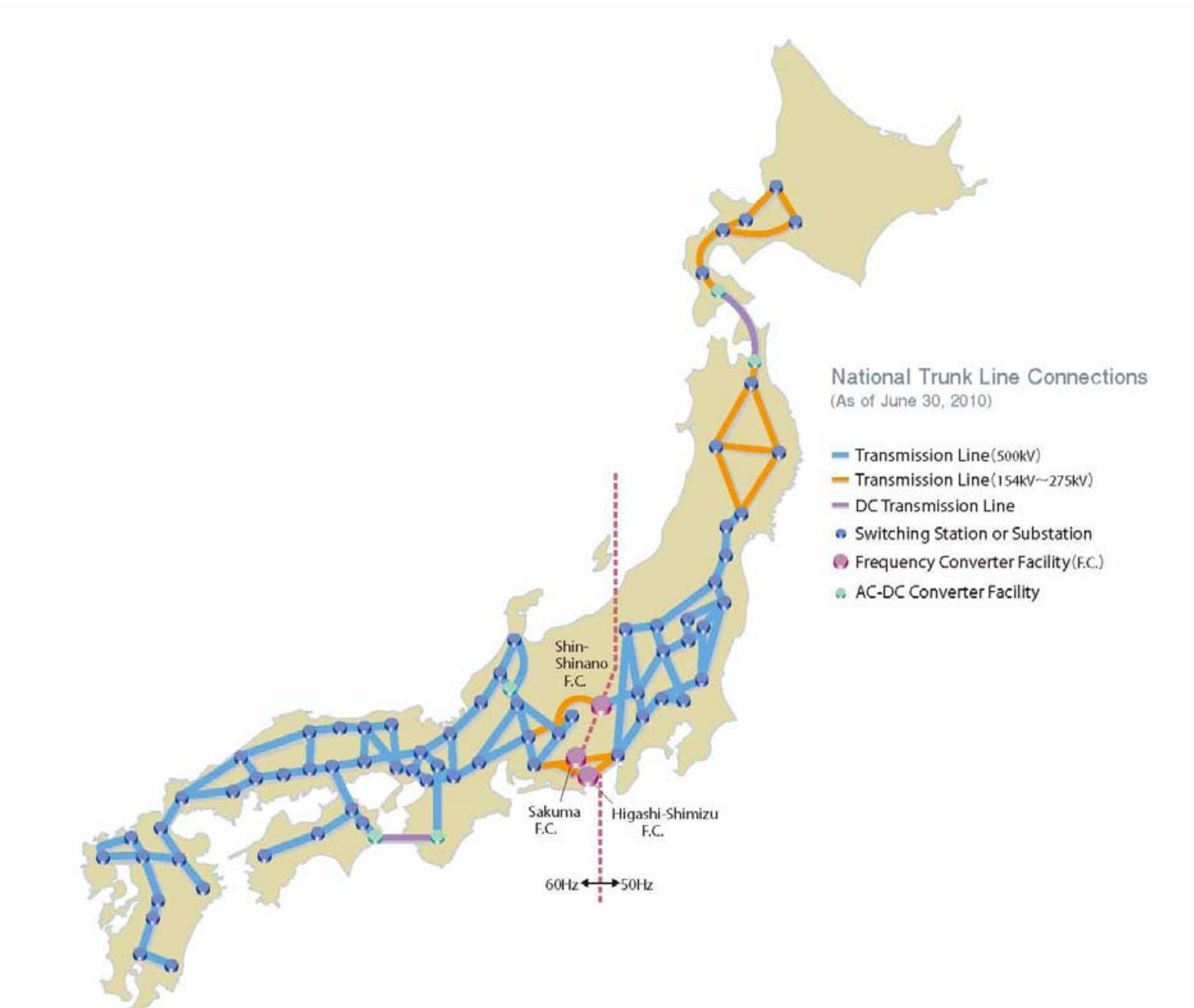
[17] See, for example, Mark Fischetti, "Japan's two incompatible power grids make disaster recovery harder", Scientific American, 3-25-2011, available as http://www.scientificamerican.com/blog/post.cfm?id=japans-two-incompatible-power-grids-2011-03-25.

Building additional fossil-fueled capacity is an option. The fastest way to add significant capacity is to bring in gas-fired combustion turbines. The Thai utility EGAT has apparently agreed to disassemble two of its combustion turbines, with a total capacity of 244 MW, and ship them to TEPCO for reassembly. The expectation is that the disassembly/reassembly process will take three months, meaning, if all goes as planned, that the turbines will be available for this summer's peak electricity demand season.[18] Given sufficient gas supplies and supply infrastructure, it is conceivable that additional combustion turbines, perhaps mounted on barges at Tokyo-area ports, could also be connected in time to provide power for the summer peak. Combustion turbines, however, typically are not as efficient (sometimes under 30 percent efficiency) as baseload gas-fired power plants (which are over 40 percent efficient), and are not designed to run at high capacity factors, meaning that they are not normally used for supplying power day in and day out. In addition, the imported gas fuel that they use, derived from liquefied natural gas (LNG) brought in by ship, is expensive, particularly if the LNG must be purchased on the short-term "spot" market.

In the medium term, the most likely and fastest-to-complete supply-side option to provide significant electrical energy (GWh, as opposed to MW or GW of capacity) would be to construct gas-fired combined cycle plants fueled with relatively expensive, imported liquefied natural gas. Doing so would take two or more years, even with the most aggressive of programs. New coal-fired power plants, which are more expensive to build but less expensive to operate than gas combined-cycle plants, will probably take a minimum of three to five years to build.

[18] "Thailand to send electricity generators to help quake and tsunami-hit Japan", MCOT.net, dated 3-29-2011, and available as < http://www.mcot.net/cfcustom/cache_page/188147.html>.

Figure 8: Transmission Lines and Interconnections[19]



The net result of the supply outages caused by the earthquake, tsunami, and subsequent problems at nuclear and thermal power plants, plus constraints on power imports and short-term additions of new plants, means that the TEPCO and Tohoku service territories may be in short, or at best tight, supply situations for some time.

The Japanese Center for Low Carbon Society Strategy has released the report "The Road to Recovery: Demand-side and Renewable Energy Approaches to Meeting TEPCO/Tohoku Electricity Shortages"[20], using a capacity-sufficiency calculation similar to that used above, but

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[19]Source: Federation of Electric Power Companies of Japan (FEPC), http://www.fepc.or.jp/english/energy_electricity/company_structure/sw_index_02/index.html, visited 3/16/2011.

[20] Available (in Japanese) as http://www.jst-lcs.jp/material/20110329.pdf.

assuming that on-peak availability of generation units will be less than 100 percent, conclude that without demand-side measures (see below), available capacity in the combined TEPCO and Tohoku service territories will fall 14 GW short at the summer 2011 peak, 3 GW short at the winter 2012 peak, and 9 GW short at the summer 2012 peak.

Demand-side Resources for Power Companies Affected

Both TEPCO and Tohoku have announced power rationing programs, consisting of rolling blackouts in many areas, but exempting some regions, including earthquake-affected zones and central Tokyo[21]. With a considerable portion of their generation capacity unavailable in the short-term, and at least four and perhaps several more reactors-worth of power now gone for good, the power companies in Eastern Japan serving the areas affected by the earthquake and tsunami will be scrambling to provide electricity to their consumers. Both companies have announced power rationing. In the Tokyo Electric Power (TEPCO) area, demand management by rotating curtailments seem so far not to have been as extensive as originally expected, probably due to the fact that a lot of businesses and industries have yet to reopen following the earthquake, and that millions of consumers have lost power (and in the areas suffering most from the tsunami, sadly, the infrastructure to use it) due to breaks in the power transmission and distribution system. Another big part of the reason why curtailments have not been as necessary is that citizens of Tokyo and nearby cities and towns have made extraordinary efforts to limit their electricity use. The experience of people in Tokyo during the earthquake, including not being able to go back home due to the lack of train service, and concern about radioactive particles carried by the wind from Fukushima, has brought home to citizens that the electricity shortage problem is theirs to address, and as a result people and businesses throughout the area are conscientiously turning off their lights and air conditioners to save electricity. Curtailments have thus far been completely avoided in the Tohoku service territory as a result of conservation by citizens, coupled with reduced demand due to the earthquake and tsunami damage.

In addition, the summer months, when electricity needs tend to peak in Japan, are still approaching. It may be that the lack of generation capacity will spur TEPCO and other affected companies, and their customers, to more aggressively pursue energy efficiency measures and generation of power on-site by consumers (or distributed generation) through the use of both renewable resources (such as solar PV, and solar hot water, which have the advantage of being largely coincident with peak summer power demand) or fossil resources (natural gas-fired units, for example). The high price of electricity in Japan—which seems likely to ultimately go higher as a result of this incident—serves as an additional incentive to reduce electricity demand as much as possible. Although Japan over the

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[21]"See, for example Tohoku Joins Tepco in Rationing Power", *Japan Times*, March 16, 2010, [retrieved 17 March 2011]
<http://search.japantimes.co.jp/cgi-bin/nn20110316a5.htm>.

past several decades has been among the world's leaders in energy efficiency, these improvements have stagnated somewhat in recent years. A recent report by the International Energy Agency included a number of suggestions as to how Japan could achieve even greater energy savings with more aggressive policies.[22]The Center for Low Carbon Society Strategy (CLCSS), in the recent report described above, suggests that a combination of renewable and non-renewable distributed generation, augmented by energy efficiency and adjustment of energy demand timing in residences, can reduce or even eliminate the peak power deficits described above. Table 4 describes the CLCSS scenario for short-term, aggressive introduction of distributed generation equipment in the combined TEPCO/Tohoku service territories. The small generators described (2 kVA, or kilovolt-amps, is the equivalent of 2 kW) could be used in residences, either as stand-alone generation or in combined heat and power systems that generates power and heats wate.r[23] The middle-sized generators could be used in larger multi-family buildings, or in commercial settings, and again could be configured to provide both thermal energy (space heat, space cooling, and/or water heat) and electricity, thereby increasing the efficiency of gas use over separate electricity generation and heating systems.

Table 4: Supply Assumptions for Distributed Electricity Equipment Deployment in the TEPCO/Tohoku Service Territories

	July 2011 Peak	February 2012 Peak	July 2012 Peak	
PV (made in Japan)	800	3200	4800	MW
Wind power (made in Japan)	125	500	750	MW
Small generators (2 kVA)	35	140	210	MW
Middle sized generator (300 kVA)	525	2100	3150	MW
Fuel Cells	3	10	15	MW
Total	**1**	**4**	**9**	**GW**

CLCSS also projects large potential savings from residential energy efficiency measures (lighting and appliance improvements, for example) and adjustments to the residential timing of appliance use (not using electric devices with large power draws, ranging from rice cookers to TVs to air conditioning and heating units, at peak use times).

22 International Energy Agency, "Progress with Implementing Energy Efficiency Policies in the G8." Dated July, 2009, and available as <www.iea.org/G8/docs/Efficiency_progress_g8july09.pdf>.; "The way to recovery: How to design infrastructure under the lack of electricity supply", Center for Low Carbon Society Strategy, dated 3-29-11, and available (in Japanese) as <http://www.jst-lcs.jp/material/20110329.pdf>.

23 Small cogeneration units for household use have been available for several year from at least one company (for example, see Honda Corp., Honda and Climate Energy Begin Retail Sales of freewatt™ Micro-CHP Home Heating and Power System, dated April 3, 2007, and available as ,http://corporate.honda.com/GovRelations_DCTM/Press_Releases/MCHP_Sales_Release.pdf>.

Evaluating a "Package" of Aggressive Demand-side and Renewable Energy Options

Looking a bit further ahead, one can extrapolate the CLCSS work to develop a scenario where the deployment of the distributed generation that CLCSS describes above proceeds at a similar (admittedly very aggressive, but not necessarily overly aggressive considering the circumstances) pace for four years. In addition, a demand-side management program begins immediately in the TEPCO/Tohoku service territories that ramps up rapidly so that it saves 2 percent of sales annually by the second year of the program (consistent with the very best performances by US utilities). With this package of energy efficiency, renewable energy, and distributed generation measures, the estimated total generation and savings would be about 80 GWh annually by 2015, equal to more than 20 percent of 2009 sales in the two service territories. Summer peak savings would be 22 GW, with winter peak savings of 12 GW, about one third and one fifth respectively, of 2009 peak demand. Though some of the generation in this energy efficiency/distributed energy package is fossil fueled (likely natural gas), most of the GWh impact is from renewable generation and efficiency savings. The overall electrical energy (GWh) savings and generation from the package are the equivalent of about 12 GW of baseload power (before adjusting for avoided transmission and distribution losses), or more than the capacity of the nuclear plants that have been taken off-line (whether temporarily or permanently) as a result of the earthquake and its aftermath. Table 5 summarizes the key assumptions in preparing this estimate. Note that fuel (or electricity) savings due to avoided water or space-heating fuel use have not yet been counted in this estimate, but would accrue to deployment of combined heat and power systems.

Table 5: Modified Four-year Energy Efficiency/Distributed Energy Scenario for the TEPCO/Tohoku Service Territories: Assumptions and Results

					Assumed Peak Coincident Factors		Implied MW Coincident Peak	
Generation Type	**Deployment by 3/31/2015**		**Assumed Capacity Factor**	**Energy Output (GWh)**	**Summer**	**Winter**	**Summer**	**Winter**
PV (made in Japan)	*6,400*	*MW*	*13.7%*	*7,680*	*60%*	*10%*	*3,840*	*640*
PV (including imports)	19,200	MW	13.7%	23,040	60%	10%	11,520	1,920
wind power (made in Japan)	*1,000*	*MW*	*30%*	*2,628*	*30%*	*30%*	*300*	*300*
wind power (including imports)	3,000	MW	30%	7,884	30%	30%	900	900
small generator (2 kVA)	*200,000*	*unit/year*						
	400	MW	35%	1,226	55%	55%	220	220
middle-sized generator (300 kVA)	*18,000*	*unit/year*						
	5,400	MW	50%	23,652	65%	65%	3,510	3,510
Fuel Cells	10	MW	35%	30.66	55%	55%	6	6
TOTAL OF ABOVE	**28,010**	**MW**		**55,833**			**16,156**	**6,556**

Additionally, assume that an extremely aggressive program of energy efficiency saves
1% of total TEPCO/Tohoku electricity sales in the first year, and
2% per year annually in subsequent years, for a total of 7%
of total sales reduced. Assume that these efficiency reductions save peak at a rate of 0.228 kW/MWh saved
(meaning that demand savings is twice as likely to contribute to peak savings as baseload power), then
on average, both summer and winter. Then
total energy savings by Spring 2015 would be 25,141 GWh, and summer and winter peak savings would be
each 5740 MW.

Total generation and savings from distributed generation and energy efficiency programs above:
80,974 GWh, which is the equivalent, assuming a capacity factor of 80%
or the equivalent of about 11,555 MW of nuclear (or other baseload) power.

Before we detail the estimated cost of the above package of measures it is important to note a few caveats to our analysis. First, the unit costs of the elements of a package like that above, and of the central power station supply alternatives that might be implemented instead, are subject to some uncertainty, especially where technology costs are changing rapidly (solar PV), are very site-specific (wind), or where costs may be affected by policies adopted in the aftermath of the Fukushima accident. The overall cost of the package is sensitive to these parameters to varying degrees. Package costs are also sensitive to the discount/interest rate used for the analysis. A real discount/interest rate of 4 percent/year was used for the analysis below[24]. Second, the costs of both the package of (largely) demand-side measures and the alternative central-station option depend to some extent on the future cost of natural gas, which is uncertain. Third, we have not yet attempted to evaluate the impacts of configuring the distributed gas-fired generation as combined heat and power units. Doing so would increase the capital costs somewhat, but would also reduce net gas use by the package substantially (perhaps by 50 percent or more), resulting in ongoing gas and carbon dioxide emissions (CO_2) savings. Fourth, both the EE/RE/DG package and the package of nuclear

[24] Interest rates in Japan have been near zero in recent years, but it unclear whether it is appropriate to apply such low interest rates to analysis of long-lived infrastructure.

and gas-fired central-station power plants to which it is compared would require transmission and distribution upgrades, albeit of radically different kinds. The net cost of these upgrades has not been estimated for either scenario (for more on this topic, see "Next Steps and Institutional Implications" in Section 3 of this report). Fifth, some of the investments in energy efficiency (and possibly in distributed generation as well) may not, in fact, be incremental, if they are undertaken in coordination with rebuilding of earthquake and tsunami-affected communities and infrastructure. Finally, this package of alternatives has not been optimized to reduce costs or to maximize energy savings or CO_2 emissions impacts. Doing so is well beyond the scope of this paper, but is a worthy exercise for Japanese researchers in the coming months.

Table 6 presents our initial estimate of the costs of the renewable energy and distributed generation elements of the full package of energy-efficiency, renewable energy, and distributed generation (hereafter, "EE/RE/DG") measures. As such, it does not include the calculations used to estimate energy efficiency cost and performance. A version of this table with notes on assumptions and sources (including on energy efficiency) is provided as a part of Attachment B. Overall, we estimate that the package of energy-efficiency, renewable energy, and distributed generation described above would imply a capital cost of about $85 billion (about 7.3 trillion Yen) over four years, and an annualized cost of about $11 billion (about 0.9 trillion Yen) per year after the fourth year.[25] It would "produce" (generate and save) electricity at an average cost of about $0.14 (12 Yen) per kWh. Gas used by the package would produce about 12 million tonnes of CO_2 annually.[26] Assuming that the EE/RE/DG package would displace thermal generation with average CO_2 emissions of 0.6 tonnes per MWh (roughly consistent with older power plants burning a mixture of gas, oil, and coal), the package could displace about 50 million tonnes of CO_2 emissions from thermal power plants.

By way of comparison (see Table 7), a package of baseload generation composed of 20 percent nuclear and 80 percent gas combined cycle capacity would entail about $35 billion (3.0 trillion Yen) in capital costs, with annualized costs of about $10 billion (850 billion Yen) per year, and levelized costs per kWh of about $0.12 (about 10.5 Yen). A key way in which the package of nuclear and gas capacity differs from the EE/RE/DG package is that the full nuclear and gas capacity will not be (or is highly unlikely to be) available within five years. The nuclear capacity probably would not be available before 2017 (the originally planned on-line date for Higashidori #2), possibly much later, and it would probably take five years or so to implement all of the gas combined-cycle units (and, significantly, their associated transmission infrastructure). The overall nuclear/gas package would emit an estimated 24 million tonnes of CO_2 annually.

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25 Costs shown are in approximately 2010 dollars and Yen.

26 Again, this is a gross figure, and does not count any savings in gas use for water heat, space heating, or other uses by implementing combined heat and power systems as part of the package.

Table 6: Estimate of Costs of EE/RE/DG Package for the TEPCO/Tohoku Service Territories: Key Assumptions and Results

Generation Type	Installed Capital Cost ($/kW)	Variable O&M ($/MWh)	Fixed O&M ($/kW-yr)	Fuel Cost ($/GJ)	Efficiency	Unit Lifetime (years)	Implied Levelized Cost ($/MWh)	Total Investment Cost ($ million)
PV (made in Japan)	4,500	0	25	0	N/A	20	$297	$ 28,800
PV (including imports)	3,500	0	25	0	N/A	20	$235	$ 67,200
wind power (made in Japan)	2,000	1	30	0	N/A	20	$68	$ 2,000
wind power (including imports)	1,500	1	30	0	N/A	20	$54	$ 4,500
small generator (2 kVA)	400	15	10	$16	33%	15	$190	$ 160
middle-sized generator (300 kVA)	600	15	10	$16	40%	20	$159	$ 3,240
Fuel Cells	4,000	15	10	$16	50%	20	$130	$ 40
TOTAL INVESTMENT COSTS							$ 75,140	(million $)
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE							$ 176	per MWh
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE							$ 9,851	(million $)
CO_2 EMISSIONS FROM PACKAGE ABOVE AT		55.8	te/TJ consumed (IPCC Tier 1 value)				12.64	million te
TOTAL INVESTMENT COSTS							¥ 6,387	(billion Yen)
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE							¥ 15.00	per kWh
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE							¥ 837	(billion Yen)

Table 7: Estimate of Costs of Central-station Generation Package for the TEPCO/Tohoku Service Territories: Key Assumptions and Results

Generation Type	MW Capacity (Note 11)	Installed Capital Cost ($/kW)	Non-fuel Variable O&M ($/MWh)	Fixed O&M ($/kW-yr)	Fuel Cost ($/GWh nuclear, $/GJ gas)	Efficiency	Unit Lifetime (years)	Implied Levelized Cost ($/MWh)	Total Investment Cost ($ million)
Nuclear	2,464	$ 6,000	$ 3.50	$ 80	$ 12	NA	40	$ 66.84	$ 14,786
Gas Combined-Cycle	9,241	$ 1,100		$ 44	$ 16	55%	25	$ 120.06	$ 10,165
Gas Simple Cycle	11,085	$ 900		$ 36	$ 16	38%	25	$ 392.25	$ 9,977
TOTAL INVESTMENT COSTS								$ 34,928	(million $)
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE								$ 123.02	per MWh
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE								$ 9,962	(million $)
CO_2 EMISSIONS FROM GAS-FIRED GENERATION ABOVE AT				55.8	te/TJ consumed (IPCC Tier 1 value)			24.32	million tonnes
TOTAL INVESTMENT COSTS								¥ 2,969	(billion Yen)
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE								¥ 10.46	per kWh
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE								¥ 847	(billion Yen)

Implementing a package of (largely) demand-side measures like the EE/RE/DG package described above sufficiently rapidly and aggressively to make a significant difference to electricity availability in the near-term will require strong institutional support. Obtaining that support may well require significant changes in the organization and operation of Japan's electricity (and more broadly, energy) sector institutions, both in ways that have been contemplated previously and in ways that have not. We address this topic briefly under "Next Steps and Institutional Implications" in Section 3, below.

Medium-term Implications for TEPCO and Tohoku Service Areas

Even if the reactor cores and spent fuel pools in the affected nuclear power plants are stabilized immediately, a number of questions remain, the answers to which will determine what the electricity supply system in Japan looks like for years to come. For example, how many reactors affected by the earthquake will ultimately pass inspection and be able to be restarted? Will analysis of the results of the earthquake uncover generic problems that may cause other reactors, even those not affected by the earthquake, to need to be shut down?

On the demand side, what fraction of the industrial, commercial, and residential infrastructure that was affected by the earthquake will be rebuilt, as opposed to moving elsewhere? At what level of energy efficiency will infrastructure be rebuilt? Depending on how these uncertainties play out, the earthquake-affected area of Japan could be short of electricity for many years.

It seems clear, however, that the four affected Fukushima I reactors will not be reparable, and it may well be, given the explosion at Fukushima I unit 4, that a combination of damage and radioactive contamination at units 5 and 6 and/or problems with the spent fuel pools in those units will render those units un-repairable as well. Thus units 1 through 4, and maybe the entire Fukushima I complex, will need to be "decommissioned" — dismantled, decontaminated and safely disposed of—at a cost that will run into the tens of billions of dollars.

It is possible that other power plants—a total of seven TEPCO, four Tohoku, and one Japan Atomic Power (the 1100 MW Tokai unit 2) nuclear reactor units, as well as a number of coal- and gas-fired plants that went off-line following the earthquake — will also be affected, and some may ultimately be found to be either un-repairable or require lengthy repairs.

In order to provide electricity to their customers during this period, TEPCO and Tohoku will need to use their existing fossil fuel-fired plants much more heavily, probably for many years, than they would have had they been able to use the nuclear plants. In addition to incurring extra costs for purchase of fossil fuels, this will result in emissions of probably tens of millions of tonnes of additional emissions of greenhouse gases and other pollutants, although the extent of these additional emissions, so far as we know, has yet to be estimated (beyond the extremely preliminary estimates we provide below).

3. Scenarios for the Evolution of the TEPCO and Tohoku Electric Power Company Systems in the Coming Years

As is clear from the description of the status of the TEPCO and Tohoku Electric Power Company electrical systems provided above, providing electricity to a recovering regional economy in the coming years, working without the generation resources destroyed or disabled by the earthquake, tsunami, and nuclear accident, will be daunting. How those electricity supplies are restored, and at what pace, will have a profound impact on the lives and livelihoods of the people in the affected areas and beyond. Below we outline several possible "scenarios" of recovery of the electricity system. In these early days, it is impossible to explore these scenarios in quantitative or even qualitative detail. Rather, we have tried to provide a set of questions and issues for further exploration as the nuclear crisis unfolds, and as the parameters of the required electricity system recovery become more evident. We should note that all of these scenarios assume implicitly that the ongoing problems with the troubled reactors and spent fuel pools at Fukushima I are ultimately addressed such that impacts do not reach the "Chernobyl level". That is, we assume that the TEPCO/Tohoku areas are not, when the situation is resolved, subjected to radioactive fallout sufficient to make substantial portions of the area unlivable.

"Best Case" Scenario

Based on what we are seeing today, (April 10th, 2011), the combination of structural damage and radioactive contamination make it unlikely that any of the Fukushima I nuclear plants will ever be restarted. Units 1 through 6 will need to be decontaminated and decommissioned, a process that will be lengthy (years, perhaps a decade or more), expensive (many billions of dollars), and also difficult to the point of requiring the importing of experts with experience in recovering from the U.S. Three Mile Island and Soviet Chernobyl incidents. It is likely that new technologies and methods will need to be developed to deal with the problems that the cleanup will pose. Japanese policies toward movement and storage of spent fuel may need to change as well, in order to deal with the considerable quantities of spent fuel on the site (assuming they remain intact, and even more so if they are physically compromised) that at present have nowhere to go.

Beyond Fukushima I, a Best Case might allow the currently off-line Onagawa nuclear plant (Tohoku) back on line soon, perhaps before the period of summer peak demand. It is at present unclear what damage the Fukushima II plants may have sustained, though they appear to have been shut down successfully, albeit with some difficulty. It seems likely that the Fukushima II plants will require a fairly lengthy inspection and some repairs before they are restarted (assuming the inspection turns up no major problems). Even at that, public concern may be a factor in keeping the Fukushima II plants offline longer. A Best Case might have these plants back on line in two years. The Higashidori and Tokai plants will require similar structural assessments and repairs, and might take a year or more to be brought back on line. Further, three units (totaling 3300 MW) of the Kashiwazaki-Kariwa nuclear plant, which was affected by a 2007 earthquake, are currently undergoing inspection and evaluation for earthquake resistance, possibly continuing through April.[27]

[27] "Status of the Inspection and Restoration Works Performed after the Niigata-Chuetsu-Oki Earthquake" (as of March 10), Press Release , Tokyo Electric Power Company, 10 March 2011 [accessed 18 March 2011], http://www.tepco.co.jp/en/press/corp-com/release/11031001-e.html.

TEPCO had recently announced and begun the construction of a new 1385 MW nuclear unit at Higashidori, with operations slated to start in March of 2017.[28] This unit has been planned for some time. Under a Best Case scenario, it would be on line by its planned date, but it is certainly possible that the earthquake and its aftermath could force a slowdown in construction while evaluations of the seismic safety of the site and reactor design, as well as of the existing reactor unit present at the site, are carried out.

The joint thermal power plants at Haramachi (2000 MW) are heavily damaged, and might take six months or so to be restarted under a Best Case scenario (Figures 9 and 10). The status of the approximately 7000 MW of TEPCO's thermal power plants that were placed offline at the time of the earthquake is not entirely certain, but we assume in this Best Case that the TEPCO thermal plants can be brought back on line relatively quickly.[29]

[28] Tsuyoshi Inajima and Michio Nakayama, "Hitachi, Toshiba May Win 200 Billion-Yen Nuclear Plant Order", Blookberg, dated 1-26-2011, and available as http://www.bloomberg.com/news/print/2011-01-27/hitachi-toshiba-may-win-200-billion-yen-tokyo-electric-nuclear-contracts.html.

[29]On 17 March, a TEPCO vice president said its priority is to get the Kashima thermal power station (4400 MW) back on line as soon as possible, but provided no estimate of the time required. He raised the possibility of using several 300 MW emergency power generators attached to telecom companies, but the possibility seemed slim.

「鹿島火力発電所の復旧急ぐ」東電副社長 , 日本経済新聞, 17 March 2011, [retrieved 18 March 2011],. http://www.nikkei.com/news/latest/article/g=96958A9C93819696E3E5E296E08DE3E5E2E1E0E2E3E3E2E2E2E2E2E2.

Figure 9: Damage at thermal power plant, Haramachi, in South-Soma (Fukushima prefecture)[30]

[30]東北地方太平洋沖地震に伴う東北電力の電力設備被害状況写真, Tohoku Electric Power Company, 13 March 2011, [retrieved 18 March 2011], http://www.tohoku-epco.co.jp/emergency/9/1182292_1807.html.

Figure 10: Damage to transmission lines, Otsuchi, Iwate prefecture[31]

In a Best Case scenario, then, about 4700 MW of nuclear generating capacity is gone, and must be replaced or otherwise compensated for by supply- or demand-side resources. Further, 2700 MW of capacity that were to be completed at Fukushima I during the next decade seem highly unlikely to be so, and the generation that would have come from those units will need to be replaced or compensated for as well. Another 6600 MW of nuclear capacity is likely to be offline for one to three years, 3300 MW at the Kashiwazaki-Kariwa plant is offline for inspection, and 4000 MW of thermal capacity seem likely to be offline through the summer. On March 17, a TEPCO vice-president said that full operation of the Kashiwazaki-Kariwa NPP will be difficult, due to emotion about nuclear power.[32] TEPCO's total generation in 2009 was about 300 TWh, of which nearly

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[31] **東北地方太平洋沖地震に伴う東北電力の電力設備被害状況写真**, Tohoku Electric Power Company, 13 March 2011, [retrieved 18 March 2011], http://www.tohoku-epco.co.jp/emergency/9/1182292_1807.html.

[32] **「鹿島火力発電所の復旧急ぐ」東電副社長 , 日本経済新聞**, 17 March 2011, [retrieved 18 march 2011], http://www.nikkei.com/news/latest/article/g=96958A9C93819696E3E5E296E08DE3E5E2E1E0E2E3E3E2E2E2E2E2E2.

one-third was from nuclear power. [33] This fraction itself is down from the 38% of TEPCO generation nuclear power supplied in 2006, before the 2007 Niigataken Chuetsu-Oki earthquake.[34]

Our analysis of this “Best Case” scenario is necessarily preliminary and incomplete, but for the TEPCO service area, some of the implications appear to be as follows. The annual output of remaining operating nuclear units totals 4912 MW (this is the TEPCO nuclear capacity as of 3/17/11 that was not affected by the earthquake and subsequent events). At a 90% capacity factor, which is probably higher than would be expected in the coming year under the circumstances, the output of these reactors would be about 39 TWh/yr. As nuclear generation accounted for about 90 TWh in 2009, this implies that if demand is the about same in the coming year as it was in 2009 (though, given the impacts of the earthquake on infrastructure, the economy, and the consumption patterns of Tokyo-area residents, lower consumption is definitely possible) then an additional 51 TWh would have to be generated by fossil fuel plants that was not in 2009. At an average emission factor of 0.6 tonnes CO_2/MWh (roughly reflecting the non-nuclear fraction of TEPCO’s generation mix of mostly oil- and gas-fired thermal power plants) this implies annual additional CO_2 emissions of about 31 million tonnes. Given that TEPCO's hydroelectric generating capacity is virtually all (all but a few percent) "pumped-storage" hydro, that is, hydroelectric capacity built to provide peaking power for the system by storing baseload (night-time) coal-fired and nuclear generation by pumping water uphill to store energy, virtually all non-nuclear generation will be fossil-fueled. If demand in 2011 is similar to 2009 levels, TEPCO's thermal plants would be called upon to produce about 260 TWh of output in 2011, which implies an impossible capacity factor of nearly 100% for the thermal power plants available now, and a still-very-high 95% if the all of the thermal power plants that were shut down during the earthquake are expected to be restarted quickly. Either way, this is a significant increase from the 65% average capacity factor experienced for thermal plants in 2009. We do not know whether all of the thermal plants on the TEPCO system can sustain significantly higher capacity factors, or whether sufficient fuel will be available—that is, whether the operable delivery and storage capacity for the needed additional gas, oil and coal—is sufficient to provide the needed level of thermal generation.

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[33]Tokyo Electric Power Company, “Annual Report 2010,” [retrieved 17 March 2011], http://www.tepco.co.jp/en/corpinfo/ir/tool/annual/pdf/ar2010-e.pdf.

[34] “State of the Power Station After the 2007 Niigata-Chuetsu-Oki Earthquake”, Tokyo Electric Power Company [retrieved 18 March 2011] ,http://www.tepco.co.jp/en/niigata/plant/index-e.html>;
Akira Fukushima, “Report on the Earthquake Impact to Kashiwazaki-Kariwa NPP,” Nuclear and Industrial Safety Agency, September 20, 2007; Seismic Safety Expert Mission, IAEA, “2nd Follow-Up IAEA Mission in Relation to the Findings and Lessons Learned from the 16 July 2007 Earthquake At Kashiwazaki-Kariwa NPP, ‘The Niigata-ken Chuetsu-Oki Earthquake’”, Tokyo and Kashiwazaki-Kariwa NPP, Japan, 1-5 December 2008.

In the Best Case scenario, assuming no significant damage is found in the review of the other nuclear and thermal plants that have been shut down, when those plants are restarted, in perhaps one to three years, much or all of the short-term electricity supply shortage in the area may be eliminated, especially, if new fossil-fueled plants (such combined-cycle natural gas plants, which can be built in a few years if gas supplies are adequate) are built starting very soon.

"Base Case" Scenario

As a Base Case scenario for the near- and medium-term evolution of the power systems of the TEPCO and Tohoku service areas, we could see the conditions for the nuclear reactors described in the Best Case holding with the exception that the nuclear plants (other than Fukushima I) in the earthquake-affected area will undergo more lengthy inspection, and/or inspections turn up problems that must be addressed, and/or local political opposition delays restarting the plants. Inspections at some thermal plants also turn up problems that mean that they are out of service longer, or need to be replaced. In this case, the supply shortfall for the two companies is likely to last longer, perhaps several years longer (around five years total), and would need to be ameliorated by a combination of much more thermal generation, construction of new thermal generation plants (assuming availability of fuel), and probably a significant effort to curb net demand for both electrical energy and peak power. Curbing demand could take the form of rotating power cuts, agreements with industry to curtail consumption at peak times (or, in fact, to move elsewhere, as unappealing as that is for the local economy), aggressive energy efficiency programs (which would have the added benefit of reducing fuel requirements and costs), and/or encouraging residents, businesses, and industries to develop on-site generation, including solar photovoltaic (PV) generation, and gas-fired combined heat and power systems. Though northern Japan is not ideally suited to solar power production, solar PV generation offers an advantage that it will provide the most power in times of peak summer electricity demand in Japan, helping to reduce the summer peak that central electricity generating stations will need to handle.

"Worst Case" Scenario

We postulate that a "Worst Case" scenario would extend the Base Case in that all of the nuclear power plants in the earthquake area are found to have significant seismic or other damage, leading to prolonged (more than five years) retrofit requirements, and some thermal plants are found to have been compromised to the point where they cannot be repaired, and must be replaced (requiring several years). In addition, the results of inspections at the earthquake-affected power plants, coupled with nationwide public concern about the safety of nuclear plants, causes other nuclear plants (apart from the earthquake-affected plants) in the TEPCO/Tohoku service areas and maybe elsewhere in Japan to be taken off line on a rotating basis for damage assessment and/or earthquake retrofit. These additional conditions would likely result in the need for many more new thermal plants (and related fuel supplies), and an even higher reliance on demand-side measures (including power rationing) than in the Base Case to balance available supply and demand over probably five to ten years.

Next Steps and Institutional Implications

As noted above, we consider these Scenarios no more than an initial range of possible outcomes. Much more detailed consideration of the parameters and results of each of the scenarios, including, the greenhouse gas and other pollutant emissions consequences of make-up power production, the level of unserved demand over the years and the impact of unserved demand on the economy, the implications of the scenarios for future nuclear development in Japan (and, indeed, elsewhere as well), the potential impact of a strenuous energy efficiency/renewable energy effort in reducing the amount of unserved demand, and the implied costs for different scenarios.

In particular, as noted in Section 2, Japan may wish to examine carefully the costs of establishing a nationally integrated "smart grid" that enables intermittent renewables to be scaled up alongside a massive program of fast, super-efficient end use efficiency in all sectors. This approach may be cheaper, faster, and more resilient in the short and the long-run than relying on coastal coal and nuclear-fired power plants to make up for the immediate and long-term shortfalls in generating capacity. It also may allow Japan to accelerate the process of building a new energy infrastructure where consumer-sited devices such as small cogeneration (even household) systems generate and store electricity and heat to meet on-site demands and, through integration with the "smart grid", demand for peak power as well. These cogeneration systems exist today, and Japan is among the leaders in cogeneration technologies, particularly for the residential market. The advent of the electric car provides both an additional challenge and an opportunity. Millions of electric cars, connected to the smart grid when not in use, could store intermittent (such as wind and solar) power, and even feed it back to the grid to meet peak demand. "Hybrid" vehicles (cars and trucks with mostly electric drive systems but internal combustion engines configured to generate electricity) could be set up to act as generators to meet peak needs when not in use.

Two considerations not yet fully explored in the rough comparison of the EE/RE/DG and central-station power scenarios provided in Section 2 concern incremental transmission and distribution costs, and the relative timing of energy supplies.

As noted above, our comparison of the two scenarios for filling in for some of the power supplies that are now, and will at least to some extent be in the future, missing from the TEPCO/Tohoku systems as a result of the earthquake and its aftermath does not account for the upgrades to the transmission and distribution systems that each scenario would require. The EE/RE/DG scenario, or at least the renewable energy and distributed generation elements of same, will require the deployment of a number of "smart grid" technologies to, among other functions, allow solar PV power to be connected to the grid to maximum effect, and to allow the control of distributed gas-fired generation to help to meet system loads. Smart grid elements can go well beyond these functions, of course, in that they can (for example) help consumers to adjust the timing of their electricity use so as to avoid system peak (and peak demand charges, if applied), and allow for the control cycling of some devices—such as storage water heaters, air conditioners, possibly refrigerators, and other devices that end-users agree to put under utility control—so as to reduce overall system peak. The EE/RE/DG scenario would also likely require some (relatively modest) transmission upgrades to handle the added wind power, depending on the location of the wind farms. In the central-station scenario, some transmission upgrades and additions, including new transmission lines and substations, would likely be required to integrate the new power plants into the grid. The extent and costs of these upgrades and additions would be, of course, highly dependent on where the stations are placed, including whether they are sited near existing plants with spare transmission capacity, and how near they are to main transmission lines. Overall, since the types of transmission and distribution (T&D) changes that would be needed in the two scenarios are quite different, it is difficult to judge without a detailed study, whether these costs would be greater or less for one of the two scenarios. Our very rough guess is that adding T&D costs would add perhaps 5 to 20 percent to the overall capital costs of the scenarios, and would not change the relative costs of the two scenarios very much. Further, an argument can be made that the smart-grid-type investments will be needed in the TEPCO/Tohoku service areas anyway, in order to manage demand in the next few years and prepare northern Honshu for the electricity systems of the future, and thus smart grid investments are really, to a large extent, required under both scenarios. Evidence for this position is contained in a recent report by the U.S. Electric Power Research Institute, which found that the costs of smart-grid improvements, while substantial, are outweighed by the benefits of the improvements by a factor of about three to six or more.[35]

Another key difference between the EE/RE/DG scenario (or any scenario emphasizing energy efficiency and distributed generation) and a central-station alternative is that the former starts producing (saving and generating) energy much faster than the latter. Even with the smoothest of construction and licensing schedules—and recent reports indicate that TEPCO may be exempted from environmental impact studies requirements on power plant expansion and addition projects[36]—gas-fired generation is unlikely to be come on line for two to three years, coal-fired power for four to five years, and nuclear power longer still, perhaps six to seven years at a minimum.

[35] Electric Power Research Institute (EPRI), Estimating the Costs and Benefits of the Smart Grid A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid, dated March, 2011, and available as http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=404&RaiseDocID=000000000001022519&RaiseDocType=Abstract_id.

[36] See, for example, Nikkei.com, "Tepco Gets Pass On Impact Studies For Power Plant Expansions", dated April 5, 2011, and available as http://e.nikkei.com/e/fr/tnks/Nni20110404D04JFA18.htm.

Given damage to power transmission, road, port, and fuel supply systems, this timing may be optimistic. Relative to a central-station supply scenario, the EE/DG/RE scenario could begin to supply energy and power in a matter of months, thus reducing, in the short run, the amount of unserved load.. The value of unserved load varies from place to place, and study to study, but is typically estimated to be substantial. A recent study for Germany—a mature industrial economy like Japan's—suggests that the value of unserved load is about 6.1 Euros (2007) per kWh, or roughly $8.8/kWh (2010 dollars), or 740 Yen/kWh[37]. Although this and most other estimates of the value of unserved load are likely derived to cover situations where unserved load is a much smaller fraction of total load than is now the case in the TEPCO/Tohoku service territories, using it as a benchmark suggests that the approximately $1 billion per year difference between the annualized costs of the EE/RE/DG and central-station power supply scenarios we considered in Section 2 would be erased if the EE/RE/DG scenario served just 120 GWh of lost load not served in the period before the central-station plants could come on line. Since 120 GWh is just a fraction of a percent of the annual output of the EE/RE/DG package, the cost difference between the packages seems certain to easily be overcome by the value of the additional unserved load implied in the central station scenario, as a result of the later on-line dates of the large central-station plant versus the first few years of EE/RE/DG capacity.

We would not claim that the comparison of EE/RE/DG and central power station alternative for replacing TEPCO and Tohoku supplies affected by the earthquake and its aftermath is either exhaustive or definitive, in and of itself. What the comparison does clearly indicate, however, is that further, more encompassing and detailed (but rapid) studies are needed are needed in order to determine the best response to the current supply shortfall, not just in terms of short-term convenience, but also for the long-term electricity system and energy security future of northern Honshu in particular and, in fact, all of Japan.

Somewhat relatedly, Japan may wish to take this opportunity to study the possibility of changing the frequency used by the electricity system in the northern part of Honshu (and, presumably, Hokkaido) from 50 Hz to the 60 Hz used in the rest of Japan. Doing so would involve vast, expensive, and probably very painful changes in both end-use and electricity supply infrastructure, but would allow the power grids of Japan to be much better integrated, and possibly more ready and able to absorb imports of power from Russia, should they become available. Making the change to 60 Hz might also improve markets for high-efficiency electrical appliances and equipment, both by broadening the consumer base (60 Hz power is also used in the US, South Korea, and nominally—

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37 Aaron Praktiknjo, "The price of supply security of electrical energy against terrorism", prepared for Energy, Policies and Technologies for Sustainable Economies, 10th IAEE European Conference, Vienna, dated 10-09-2009, and available as http://www.aaee.at/2009-IAEE/uploads/presentations_iaee09/Pr_22_Praktiknjo_Aaron.pdf. This author estimates a value of userved load for Germany of 6.12 Euros/kWh, based on loss-of-load studies in several other nations.

though not in practice—in North Korea, among other nations, though both China and Russia use 50 Hz power[38]) and by in effect forcing the purchase of new, presumably more-efficient end-use devices and supply-side equipment. A change in system frequency may well prove too complex and costly to undertake, but at this time when significant rebuilding and rebuilding costs are a given, it may be an idea that deserves at least serious consideration.

As the Fukushima I situation unfolded, the Japanese government discussed the possibility of nationalizing TEPCO to protect it from bankruptcy.[39] Doing so would apparently require a change in the laws governing utility operations in Japan, and would therefore affect the other nine electric utilities, and possibly the gas utilities as well.[40] Though the Kan administration has apparently ruled out this significant step, at least at present, it is worth considering how institutional changes in Japan's electricity sector might enhance or stymie the implementation of the types of smart-grid and demand-side options described above. Japan's ten electric utilities have traditionally been vertically integrated, meaning that each company provides all of the services, from generation through transmission and distribution, required to serve its consumers with electricity. A process of liberalization of the sector begun in the 1990s includes laws that have since 2000, at least nominally, offered progressively smaller (in terms of average power demand) electricity consumers a choice of electricity providers. It is not, however, clear to us whether, in practice, this market liberalization has resulted in many customers being served by non-utility suppliers or by utilities outside of their home area.

Aggressively pursuing demand-side management and renewable power generation, and building and operating a "smart grid" with the integration of literally millions of distributed electricity generation

[38] Since Russia is the most likely source of imports of power to Japan, the fact that Russia uses a 50 Hz system would seem to argue for northern Honshu and Hokkaido to remain at 50 Hz. It is our guess, however, that a transmission line linking Russia and Japan would be a direct current (DC), not alternating current (AC) line anyway, and the new DC-AC converters required to interconnect a line from Russia to the Japanese grid could probably be designed to output either 60 Hz or 50 Hz AC power at approximately the same cost.

[39] See, for example, David Jolly, "Japan Weighs Nationalizing a Stricken Utility", The New York Times, dated 3-29-2011, and available as http://www.nytimes.com/2011/03/30/business/global/30tepco.html?_r=1&hp.

[40] Similar to its electricity sector, Japan's gas sector—nearly all of which is dependent on imported liquefied natural gas (LNG)—is typically divided into separate companies that run LNG import terminals and serve a specific area. These areas have historically been poorly linked, or not at all linked, by "trunk" pipelines, making it difficult to move gas between the major demand areas in Japan. This organization protects the markets of local companies, but tends to help keep prices high, and stymies Japan's ability to participate in international gas projects, including imports of gas by pipeline from Russia. Japan's approach to the gas sector is in contrast, for example, to that of the Republic of Korea, which has built and national trunk pipeline to connect the country's LNG terminals.

and/or storage sites and devices, will require an extreme level of coordination between energy end-users, and the (likely non-utility) vendors that support them, and those organizations that plan and operate Japan's transmission and distributions systems. This level of coordination has never been needed before, and the current institutional structure of Japan's power sector is likely not geared to the task. A number of voices have, over the years, suggested the partitioning of Japan's power sector into different components, including different companies/organizations responsible for generation, transmission, and distribution of electricity, often with different companies or organizations responsible for demand-side managements. Many other countries, including the United States (in which electricity is in many regions provided by "System Operators" independent from generation or distribution companies), as well as the Republic of Korea, have implemented or are in the process of implementing such changes. Also worth considering are changes in the way that utilities are regulated so as to provide incentives for utilities to pursue demand-side management for energy and peak power savings, and remove disincentives to pursue DSM. A number of US jurisdictions have made or are making such changes.

The tragedy of the March 11 earthquake and tsunami, coupled with the Fukushima I nuclear disaster, will force Japan to choose among different electricity futures for supplying energy service to the residents and businesses of the northern half of Honshu. The massive rebuilding required is both an incredible challenge, but also an opportunity. Meeting the energy needs of north Honshu residents with a combination of energy efficiency, renewable energy, and distributed power, and rebuilding infrastructure so as to support doing so, may well be cheaper and better for the local economy than simply rebuilding in a central-power-station-supply mode, and will also help to advance national goals and commitments such as development and deployment of advanced technologies and reduction in emissions of greenhouse gases and other pollutants. Doing so, however, will require a significant departure from the way that electricity has traditionally been supplied and used in Japan, and will require massive changes in well-established institutions, both private and public. Significantly included among those institutions that must change in order to embrace a new approach to how electricity is produced, stored, and used are those with the responsibility to regulate the electricity sector (and the energy sector more broadly). Making institutional changes in the sector will likely require pressure from numerous voices both inside and outside Japan. Whether the earthquake and its aftermath can provide the spur needed to begin such changes remains to be seen.

Finally, the electricity sector choices placed before Japan are complicated by the future of the country's commitment not just to nuclear power, but to the handling of nuclear spent fuel. Japan's policy has long been to reduce the amount of spent fuel in storage by reprocessing it to separate plutonium from depleted uranium (that is, from the original low-enriched uranium in the fuel, which has been depleted of much of its original content of the uranium-235 isotope) and other products of the nuclear reaction. The plutonium thus separated is combined with uranium to create mixed oxide

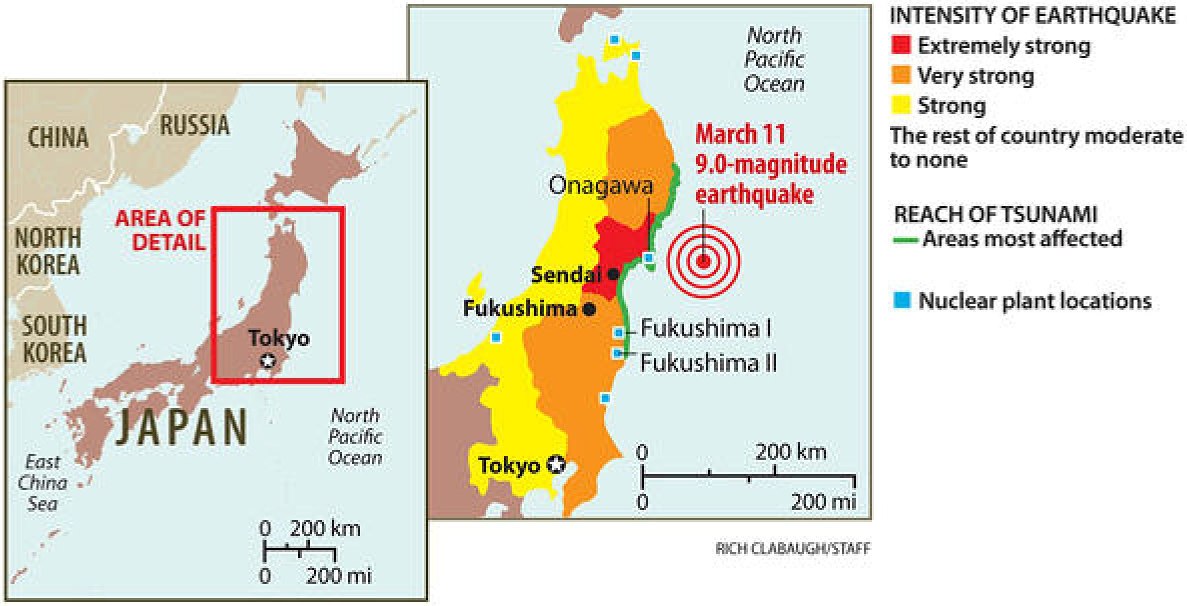
(MOx) fuel, which can be used in light water reactors. The use of MOx fuel was being tested in a relatively low fraction (6 percent) of the reactor core in unit 3 of the Fukushima I plant at the time of the earthquake. A key rationale for reprocessing spent fuel and using MOx fuel is to conserve the world's supply of uranium. A number of researchers, including one of the authors of this report, have found that, in general, global uranium supplies are sufficient for many decades, perhaps centuries, of reactor use, and that the costs of reprocessing and MOx fuel use far outweigh any savings from both the front end (fuel provision) and back end (nuclear waste management) of the nuclear fuel cycle. It seems likely that a shift in the Japanese electricity sector towards smart-grid, energy efficiency, renewable energy, and distributed generation, probably displacing significant growth (and perhaps net capacity) in the domestic nuclear energy industry, would also affect the future of reprocessing, and by extension, nuclear spent fuel management in Japan. Institutions, both private and public, that have been built to serve and promote Japan's nuclear energy and reprocessing-focused policies may find themselves obliged to change radically. Such changes will, to say the least, be difficult.

Attachment A: Status of Nuclear Power Plants in the Earthquake/tsunami-affected Area

An earthquake of magnitude 9.0 occurred at 2.46 pm local time on March 11, 2011 at a depth of 32 km in the Pacific Ocean 130 km east of the industrial city of Sendai on Honshu.[41] This earthquake is the most powerful experienced in Japan, and was followed by many aftershocks of considerable magnitude (Figures A-1 and A-2). At the time of writing these were continuing, and there was a high likelihood of further substantial shocks. The effects of the earthquake in Pacific coastal regions of northeast Japan were greatly exacerbated by the tsunami generated by the earthquake which hit the coast some minutes later at heights of 10 meters or more.

[41]Location: 38.322°N, 142.369°E. For details see United States Geological Service, "*Magnitude 9.0 - NEAR THE EAST COAST OF HONSHU, JAPAN 2011 March 11 05:46:23 UTC,",* [retrieved 15 March 2011], http://earthquake.usgs.gov/earthquakes/eqinthenews/2011/usc0001xgp/#details>; and "*2011 Sendai earthquake and tsunami,"* Wikipedia. [Retrieved 15 March 2011], http://en.wikipedia.org/wiki/Sendai_tsunami.

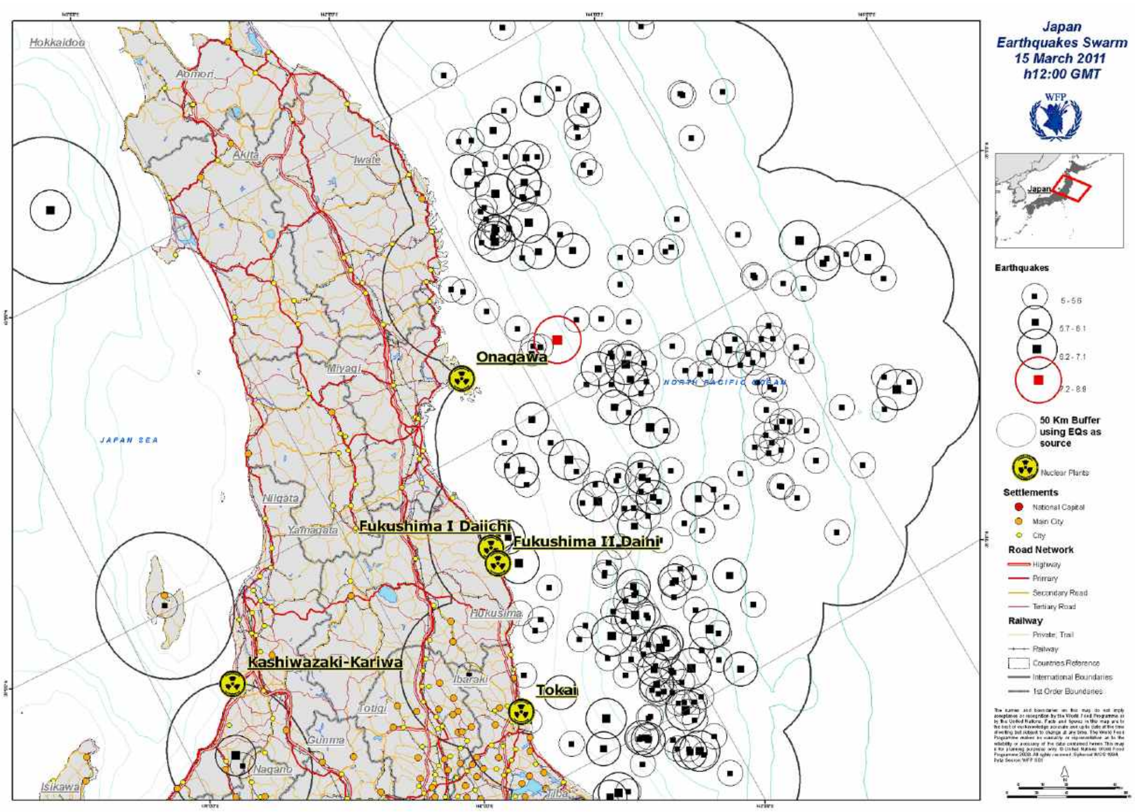
Figure A-1: Areas and Nuclear Plants Affected by Earthquake and Tsunami[42]



Although the original massive 9.0 earthquake occurred northeast of the Fukushima I and II nuclear power plants, the days following saw a large number of ongoing frequent and often powerful earthquakes bracketing the area immediately offshore from the plants. Tsunami warnings were frequently issued, and although no severe tsunamis subsequently struck this region, there remains considerable concern for a further earthquake close to the plants, with the capacity to disrupt even further the consequences of the combined original earthquake and tsunami.

[42] "Japan's Nuclear Crisis: A Timeline of Key Events", *The Christian Science Monitor*, [retrieved 15 March 2011], http://www.csmonitor.com/World/Asia-Pacific/2011/0315/Japan-s-nuclear-crisis-A-timeline-of-key-events.

Figure A-2: Japan: Earthquakes Swarm (15 March 2011)[43]



Five sets of nuclear reactors were affected by the earthquake: (from north to south) Onagawa, Fukushima I, Fukushima II, Higashidori, and Tokai. The locations of the plants most affected by the earthquake and tsunami are shown in Figure 1. When the earthquake hit, safety systems at the reactors automatically triggered control rods, which successfully shut down the nuclear chain reactions at the plants affected by the earthquake. The key to the subsequent developments at a number of the reactors in the affected zone was the ongoing generation of heat in reactors that had been shut down.

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[43]See original site for a large resolution version.
United Nations World Food Programme (WFP), "Japan: Earthquakes Swarm (15 Mar 2011)," *Relief Web*, [retrieved 17 March 2011]
http://www.reliefweb.int/rw/rwb.nsf/db900sid/RKRR-8EZLQD?OpenDocument&rc=3&emid=EQ-2011-000028-JPN.

If cooling water is not supplied to remove the heat, damage to the nuclear fuel, which consists of pellets of uranium oxide contained in long tubes made of an alloy of zirconium metal, can occur, and did in several units, as described below.

The three-unit **Onagawa** plant (total capacity, about 2100 megawatts electric (hereafter, MW refers to MWe unless otherwise stated)), is located nearly due west of the epicenter of the earthquake, and northeast along the coast from the Sendai area that was heavily affected by the tsunami that followed the quake. Two of the units of the plant were operating as of the time of the earthquake, and one was just being started up. Nuclear chain reactions in all three units were shut down immediately after the earthquake. Though all of the Onagawa plants sustained some damage to buildings and ancillary equipment, and in some cases emergency diesel generators were activated to power cooling water pumps, none of the damage seems to be major, and all reactors have been cooled to under 100 C and are considered stable ("cold shutdown").[44]

The six-year-old **Higashidori** plant (one operating unit of 1067 MW, with plans for three more units on the site) was offline for a routine check-up at the time of the earthquake. The plant required activation of emergency diesel power after the earthquake, and some seawater spilled into a floor of the plant from the secondary coolant loop, but the plant does not appear to have been heavily damaged.

The **Tokai** unit 2 reactor (1056 MW), on the east coast northwest of the quake epicenter, was also shut down automatically when the earthquake hit. Although a cooling pump apparently failed after at one point, a second pump took up the load, and the reactor is in cold shutdown[45].

The four-units of the **Fukushima II plant,** commissioned in the 1980s with about 4400 MW total (measured in gross electric output including power used in operating the power plant), were all operating at the time of the earthquake, and shut down automatically. There appears to have been some problems with the cooling systems operations after the earthquake, and a plant worker was injured and later died, but by March 15 all four units were reported to be stable and under cold shutdown.

The account of the **Fukushima I plant** is complex, and at the time of writing (10 April), still ongoing. A full accounting of the accident and situation at the plant is beyond the scope of this update, though a brief summary is provided below. For additional details about the Fukushima I plant and the accident there, see the Nautilus report referenced in the introduction to this Report,

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[44]International Atomic Energy Agency, "Japan Earthquake Update (13 March 2011, 12:35 UTC)," [retrieved 17 March 2011], http://www.iaea.org/newscenter/news/tsunamiupdate01.html

[45]International Atomic Energy Agency, "Japan Earthquake Update (15 March 2011, 14:10 UTC)" and similar at http://www.iaea.org/newscenter/news/tsunamiupdate01.html.

and more recent detailed summaries of the accident, including Wikipedia[46], The Bulletin of the Atomic Scientists[47], the International Atomic Energy Agency (IAEA)[48], and the Japan Atomic Industrial Forum, Inc.[49].

The Fukushima I plant consists of six reactor units built in the 1970s, with two more units planned for the site. The total capacity of the six existing units is about 4696 MW (gross). Three of the six Fukushima I reactor units at the site were operating at the time of the earthquake. Emergency systems were supposed to provide cooling water to the reactor cores after shut down, but these systems failed, first, apparently, because of loss of off-site power due to earthquake damage, and then because of damage to back-up diesel generators caused by the tsunami that followed the earthquake. As a result, the water cooling the fuel rods began to boil, pressure in the reactor vessels rose, and steam and other gases had to be vented from the reactor vessels into the building surrounding the reactor. In units 1, 2 and 3 of the plant, hydrogen gas generated by the interaction of steam with the zirconium metal in the fuel rods exploded in the reactor building, releasing steam and at least some radioactive cesium and iodine gases. Since the accident, the plant operator, assisted in some cases by others (including US military vessels and aircraft), has made efforts, often heroic, to stabilize the reactor cores of units 1 through 3, the spent fuel pools associated with each of the six reactor units, and the common large spent fuel pool shared by all of the units. As of 30 March, these efforts continued, with some success but also some notable failures. At least one of the reactor vessels (Unit 3) reportedly has a major crack from top to bottom[50], it is thought that the reactor core of Unit 2 has "melted down" through its steel reactor vessel and onto the concrete floor of its containment vessel[51], and earlier reports from photographs taken from the air suggests that at least some of the spent fuel pools at the plant have cracks that are allowing water to leak

46 Wikipedia, "Timeline of the Fukushima nuclear accidents", http://en.wikipedia.org/wiki/Timeline_of_the_Fukushima_nuclear_accidents

47 See, for example, Tatsujiro Suzuki, "Daily update from Japan", 4-1-2011 and before, available at http://www.thebulletin.org/web-edition/columnists/tatsujiro-suzuki/daily-update-japan, and for in-depth coverage of specific aspects of the accident and its ramifications, see "Japan in focus: A collection of the Bulletin's coverage", available as http://thebulletin.org/web-edition/special-topics/japan-focus-collection-of-the-bulletins-coverage.

48 International Atomic Energy Agency (IAEA), "Fukushima Nuclear Accident Update Log", available as http://www.iaea.org/newscenter/news/tsunamiupdate01.html.

49 Japan Atomic Industrial Forum, Inc. (JAIF), "Information Update on Fukushima Nuclear Power Station, available as http://www.jaif.or.jp/english/.

50 Energy News, "'Definite': Fukushima No. 3 has 'long vertical crack' down side reactor vessel – Nuclear Exec.", dated March 25th, 2011, available as http://enenews.com/definite-fukushima-no-3-has-long-vertical-crack-down-side-reactor-vessel-nuclear-exec.

51 Ian Sample, "Japan may have lost race to save nuclear reactor", guardian.co.uk, dated 3-29-2011, and available as http://www.guardian.co.uk/world/2011/mar/29/japan-lost-race-save-nuclear-reactor.

out[52], exposing the fuel rods stored in the pool and causing them to overheat. Significant releases of radioactive products to the air and water have occurred, and workers at the plant have suffered radiation burns as they tried to address problems. Table 1 provides the Japan Atomic Industrial Forum's summary of the status of the Fukushima I plant as of 1600 on 30 March.

Related to the nuclear sector, the large nuclear fuel reprocessing plant at Rokkasho lost power during the earthquake, and ran for several days on on-site emergency generation before grid power was restored. News reports of the status of the Rokkasho facility have been few, but it seems that it suffered at least some minor damage (a leak of liquid from a tank was reported). Rokkasho is designed to reprocess spent fuel to separate plutonium from depleted uranium and other fission products. Rokkasho has been off-line due to a technical problem. It is unclear how either whatever damage Rokkasho sustained or, perhaps more importantly, the impact of public opinion related to the Fukushima situation will affect its future operations. Rokkasho forms a significant part of Japan's plans for managing nuclear spent fuel. If it is unable to operate for an extended period, changes in those plans will be inevitable.

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[52] Energy News, "US drone uncovers 'cracks' in multiple containment pools on Friday March 18th, 2011", dated March 18, 2001, and available as http://enenews.com/us-surveillance-aircraft-uncovers-cracks-in-multiple-containment-pools-on-friday.

Table A-1: Status of Fukushima 1 Nuclear Power Plants 16:00 March 30[53]

Status of nuclear power plants in Fukushima as of 16:00 March 30 (Estimated by JAIF)

Power Station	Fukushima Dai-ichi Nuclear Power Station					
Unit	1	2	3	4	5	6
Electric / Thermal Power output (MW)	460 / 1380	784 / 2381	784 / 2381	784 / 2381	784 / 2381	1100 /3293
Type of Reactor	BWR-3	BWR-4	BWR-4	BWR-4	BWR-4	BWR-5
Operation Status at the earthquake occurred	In Service -> Shutdown	In Service -> Shutdown	In Service -> Shutdown	Outage	Outage	Outage
Fuel assemblies loaded in Core	400	548	548	No fuel rods	548	764
Core and Fuel Integrity (Loaded fuel assemblies	Damaged	Damaged	Damaged	No fuel rods	Not Damaged	Not Damaged
Reactor Pressure Vessel structural integrity	Unknown	Unknown	Unknown	Not Damaged	Not Damaged	Not Damaged
Containment Vessel structural integrity	Not Damaged (estimation)	Damage and Leakage Suspected	Not damaged (estimation)	Not Damaged	Not Damaged	Not Damaged
Core cooling requiring AC power 1 (Large volumetric freshwater injection)	Not Functional	Not Functional	Not Functional	Not necessary	Functional	Functional
Core cooling requiring AC power 2 (Cooling through Heat Exchangers)	Not Functional	Not Functional	Not Functional	Not necessary	Functioning (in cold shutdown)	Functioning (in cold shutdown)
Building Integrity	Severely Damaged (Hydrogen Explosion)	Slightly Damaged	Severely Damaged (Hydrogen Explosion)	Severely Damaged (Hydrogen Explosion)	Open a vent hole on the rooftop for avoiding hydrogen explosion	
Water Level of the Rector Pressure Vessel	Fuel exposed partially or fully	Fuel exposed partially or fully	Fuel exposed partially or fully	Safe	Safe	Safe
Pressure / Temperature of the Reactor Pressure Vessel	Gradually increasing / Decreased a little after increasing over 400℃ on 24th	Unknown / Stable	Unknown	Safe	Safe	Safe
Containment Vessel Pressure	Decreased a little after increasing up to 0.4Mpa on 24th	Stable	Stable	Safe	Safe	Safe
Water injection to core (Accident Management)	Continuing (Switch from seawater to Freshwater)	Continuing (Switch from seawater to Freshwater)	Continuing (Switch from seawater to Freshwater)	Not necessary	Not necessary	Not necessary
Water injection to Containment Vessel (AM)	(To be confirmed)	to be decided (Seawater)	(To be confirmed)	Not necessary	Not necessary	Not necessary
Containment Venting (AM)	Temporally stopped	Temporally stopped	Temporally stopped	Not necessary	Not necessary	Not necessary
Fuel assemblies stored in Spent Fuel Pool	292	587	514	1331	946	876
Fuel Integrity in the spent fuel pool	Unknown	Unknown	Damage Suspected	Possibly damaged	Not Damaged	Not Damaged
Cooling of the spent fuel pool	Water injection to be considered	Seawater Injection continue	Seawater spray continue and certain effect was confirmed	Seawater spray continue Hydrogen from the pool exploded	Pool cooling capability was recovered	Pool cooling capability was recovered
Main Control Room Habitability & Operability	Poor due to loss of AC power (Lighting working in the control room at Unit 1 and 2.)		Poor due to loss of AC power (Lighting working in the control room at Unit 3 and 4.)		Not damaged (estimate)	
Environmental effect	Radiation level: 1.05mSv/h at the south side of the office builiding, 169μSv/h at the Main gate, 78μSv/h at the West gate, as of 09:00, Mar. 30th Radioactive material was detected from milk and agricultural products from Fukushima and neighboring prefectures. The government issue order to limit shipment (Mar. 21st-) and intake (Mar. 23rd-) for some products from some areas. Radioactive iodine was detected from tap water sampled at some prefecture. Level of iodine in tap water temporally exceed the provisional legal limit for infant consumption. Radioactive Iodine, Cesium, Ruthenium, and Tellurium were detected from seawater sample collected in the sea surrounding the power station. Nuclear Safety Commission of Japan released prediction of radioactive material spread caused by the accident (Mar. 24th). This prediction was based on the calculation using computer code called SPEEDI (System for Prediction of Environmental Emergency Dose Information).==> http://www.nsc.go.jp/info/110323_top_siryo.pdf Radiation dose higher than 1000 mSv was measured at the surface of water accumulated in the tunnel for laying piping outside Unit 2 turbine building on Mar. 27th. Plutonium was detected from the soil of the Fukushima Dai-ichi NPS site on Mar. 28th. The concentration of plutonium measured is as little as in normal environment, almost the same as measured in Japan when the nuclear bomb tests were conducted in the atmosphere in the past, and not harmful to human body.					
Evacuation	20km from NPS(Mar. 12) * People who live between 20km to 30km from the Fukushima Dai-ichi NPS shall stay in the houses or buildings Mar. 15), should consider leaving Mar. 25).					
INES (estimated by NISA)	Level 5	Level 5	Level 5	Level 3	–	–
Remarks	●Progress of the work to recover injection function Water injection to the reactor pressure vessel by temporally pumps were switched from seawater to freshwater at unit-1, 2 and 3, since adverse effect such as erosion is concerned on Mar. 26th. High radiation makes difficult the work to restore originally installed pumps for injection. Removing water with high concentration of radioactive nuclides in the basement of buildings of Unit 1through 3 was partly begun on 26th but is considered to take time to complete. (3 workers were sent to the hospital after heavily exposed on March 24 and discharged on March 28.) ●Function of containing radioactive material It is presumed that radioactive material inside the reactor vessel would have leaked outside the containment vessel at unit-1, 2 and unit-3, based on the investigation of the water sampled in the turbine building from Mar. 24th to 27th . ●Cooling the spent fuel pool Steam like substance rose intermittently from the reactor building at Unit 1, 2, 3 and 4 has been observed. Injecting and/or spraying water to the spent fuel pool has been conducted on and off since Mar. 17th.					

[Source]
Government Nuclear Emergency Response Headquarters: News Release (-3/30 07:30), Press conference
NISA: News Release (-3/30 08:00), Press conference
TEPCO: Press Release (-3/30 12:00), Press Conference

[Abbreviations]
INES: International Nuclear Event Scale NISA: Nuclear and Industrial Safety Agency TEPCO: Tokyo Electric Power Company, Inc.

[Significance judged by JAIF]
Low
High
Severe (Need immediate action)

In Japan, the impact of the nuclear situation at Fukushima seems highly likely to cause the public to demand more intense scrutiny of plans for future development of nuclear power. As shown in Figure A-3, below, a number of the planned or under-construction nuclear units in Japan are near, and sometimes at, sites affected by the earthquake and its aftermath. One would expect that construction at these sites are the most likely to be delayed.

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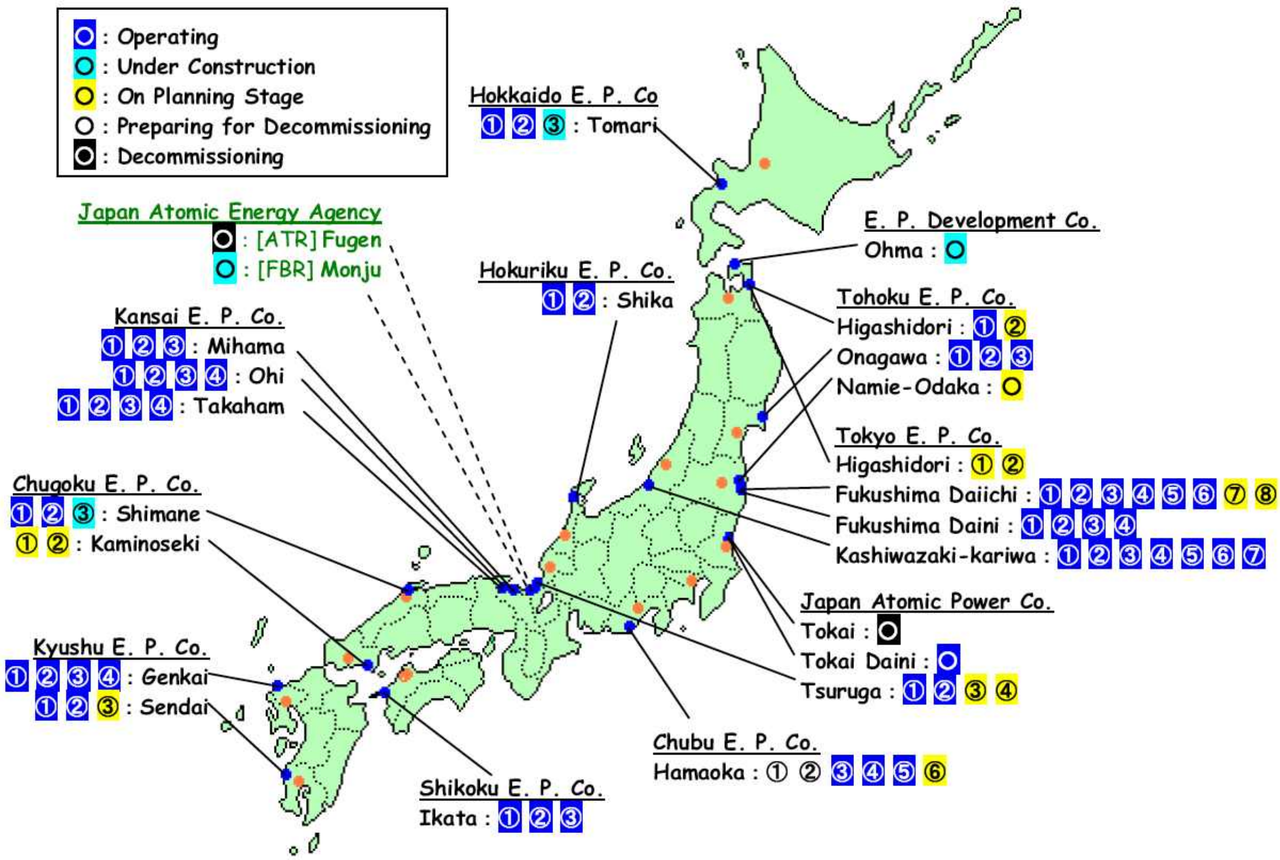
[53] Japan Atomic Industrial Forum, "Information on Status of Nuclear Power Plants in Fukushima" [retrieved 17 March 2011] http://www.jaif.or.jp/english/news_images/pdf/ENGNEWS01_1301473595P.pdf.

Figure A-3: Nuclear power stations in Japan (as of 2008) - map[54]



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[54] "Current Status of Nuclear Facilities in Japan," Japan Nuclear Energy Safety Agency, 2009, [retrieved 16 March 2011] http://www.jnes.go.jp/english/activity/unkan/e-unkanhp1/e-unkanhp1-2009/book1/.

Attachment B: Details of Estimates of Cost and Performance of EE/RE/DG and Alternative Central-station "Packages" of Measures/Infrastructure for the TEPCO/Tohoku Service Areas

Performance and Costs of Modified Version of Center for Low Carbon Society Strategy (CLCSS) EE/RE/DG Program

Last revised: 4/5/2011

Assume that the Distributed Generation Resources stipulated bu C:CSS for 2013 are actually available in 2015.
At that point, then their capacity would be:

Generation Type	Deployment by 3/31/2015		Assumed Capacity Factor	Energy Output (GWh)	Assumed Peak Coincident Factors: Summer	Assumed Peak Coincident Factors: Winter	Implied MW Coincident Peak Reduction: Summer	Implied MW Coincident Peak Reduction: Winter
PV (made in Japan)	*6,400*	*MW*	*13.7%*	*7,680*	*60%*	*10%*	*3,840*	*640*
PV (including imports)	19,200	MW	13.7%	23,040	60%	10%	11,520	1,920
wind power (made in Japan)	*1,000*	*MW*	*30%*	*2,628*	*30%*	*30%*	*300*	*300*
wind power (including imports)	3,000	MW	30%	7,884	30%	30%	900	900
small generator (2 kVA)	*200,000*	*unit/year*						
	400	MW	35%	1,226	55%	55%	220	220
middle-sized generator (300 kVA)	*18,000*	*unit/year*						
	5,400	MW	50%	23,652	65%	65%	3,510	3,510
Fuel Cells	10	MW	35%	30.66	55%	55%	6	6
TOTAL OF ABOVE	**28,010**	**MW**		**55,833**			**16,156**	**6,556**

Additionally, assume that an extremely aggressive program of energy efficiency saves
1% of total TEPCO/Tohoku electricity sales in the first year, and
2% per year annually in subsequent years, for a total of 7%
of total sales reduced. Assume that these efficiency reductions save peak at a rate of 0.228 kW/MWh saved
(meaning that demand savings is twice as likely to contribute to peak savings as baseload power), then
on average, both summer and winter. Then
total energy savings by Spring 2015 would be 25,141 GWh, and summer and winter peak savings would be
each 5740 MW.

Total generation and savings from distributed generation and energy efficiency programs above:
80,974 GWh, which is the equivalent, assuming a capacity factor of 80%
or the equivalent of about 11,555 MW of nuclear (or other baseload) power before adjusting for T&D losses.
At 0.6 te CO2 per MWh electricity output (consistent with older thermal plants burning a mixture of gas, oil,
and coal, the package above would result in gross CO_2 emissions savings of 48.58 million tonnes of CO_2.

ESTIMATES OF COSTS FOR INVESTMENTS ABOVE

Generation Type	Installed Capital Cost ($/kW)	Variable O&M ($/MWh)	Fixed O&M ($/kW-yr)	Fuel Cost ($/GJ)	Efficiency	Unit Lifetime (years)	Implied Levelized Cost ($/MWh)	Total Investment Cost ($ million)	Notes
PV (made in Japan)	4,500	0	25	0	N/A	20	$297	$ 28,800	5
PV (including imports)	3,500	0	25	0	N/A	20	$235	$ 67,200	4
wind power (made in Japan)	2,000	1	30	0	N/A	20	$68	$ 2,000	6
wind power (including imports)	1,500	1	30	0	N/A	20	$54	$ 4,500	6
small generator (2 kVA)	400	15	10	$16	33%	15	$190	$ 160	2
middle-sized generator (300 kVA)	600	15	10	$16	40%	20	$159	$ 3,240	3
Fuel Cells	4,000	15	10	$16	50%	20	$130	$ 40	1
TOTAL INVESTMENT COSTS							**$ 75,140**	(million $)	
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE							**$ 176**	per MWh	
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE							**$ 9,851**	(million $)	
CO_2 EMISSIONS FROM PACKAGE ABOVE AT		55.8	te/TJ consumed (IPCC Tier 1 value)				12.64	million te	
TOTAL INVESTMENT COSTS							¥ 6,387	(billion Yen)	
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE							¥ 15.00	per kWh	
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE							¥ 837	(billion Yen)	
COSTS CONVERTED TO YEN AT		85	Yen per dollar (4-5-2011 value, and also near average for past year)						

Interest/Discount Rate Used to Annualize Capital Costs 4%/yr. Interest rates in Japan have been very near zero in the past several years, but a discount rate of 5% is often used in social costs analyses elsewhere. We use 4%/yr as an initial value. This value may be too high for some of the investments shown above for Japan, but perhaps too low, for example, for nuclear power plant investments (for which this rate is also used below), given the financial risk that firms may place on such investments in the wake of the Fukushima accident. Government loan guarantees may be required to secure a low interest rate for such projects.

For the analysis of costs of gas-fired distributed generation and gas-fired central-station generation, we assume that average LNG import costs over the four-year period assumed for this scenario average $12 per GJ (see Note 7), and that gas terminal and transmission costs add $4 per GJ. Note that the total of these two figures is substantially less than the current commercial or residential gas rates in Japan, which can be 100% or more higher due to distribution costs and other factors. We use the sum of these two costs as an estimated societal "avoided cost" of gas in Japan, consistent with the perspective of this analysis.

A number of studies of electric energy efficiency potential in the United States have yielded average levelized costs of saved energy of approximately $30 per MWh or less (see, for example, American Council for an Energy-Efficient Economy (ACEEE), "Energy Efficiency Resource Standard (EERS)", ACEEE Policy Brief dated 1-10-2010, and available as http://www.aceee.org/files/pdf/eers_policyposition0110.pdf. Lacking specific estimates of the costs of energy efficiency in Japan, we assume that, given the relatively high level of energy efficiency that prevails in Japan, additional energy savings are available sufficient to meet the targets above at 50% more than estimated US costs, or about $45 per MWh on a levelized basis.
This implies that annual costs for the level of year-four savings shown above are about $1,131 million. These costs can be very roughly converted to total investment costs by assuming an average lifetime of energy effiiciency investments, and "back-calculating" an implied investment costs.
We assume that the average lifetime of an energy-efficiency investment undertaken during the program is 12 years. This represents a very rough average, as some investments, such as some appliances, will have a shorter lifetime, and others, such as building envelope improvements, may last much longer. Based on this average lifetime, and the discount rate above, a total investment cost for the measures included in the four-year program would be about $10,618 million dollars.

The total cost of a "package" including the energy efficiency, distributed generation, and renewable generation resources described above would be **$ 85,758** to save or produce **80,974** of electricy annually at a weighted-average levelized cost of **$ 135.63** per MWh, **¥ 11.53** per kWh, and an annual cost of **$ 10,982** per year or **¥ 934** billion Yen.

Comparison with Central Power Station Alternatives

Transmission and Distribution Losses avoided by demand-side alternatives 7.2% (Weighted average losses for TEPCO/Tohoku, based on 2009 data). Implied generation to be supplied by central power station alternatives to equal output of package above is therefore: 86,235 TWh

Generation Type	MW Capacity (Note 11)	Installed Capital Cost ($/kW)	Non-fuel Variable O&M ($/MWh)	Fixed O&M ($/kW-yr)	Fuel Cost ($/GWh nuclear, $/GJ gas)	Efficiency	Unit Lifetime (years)	Implied Levelized Cost ($/MWh)	Total Investment Cost ($ million)	Notes
Nuclear	2,464	$ 6,000	$ 3.50	$ 80	$ 12	NA	40	$ 66.84	$ 14,786	8,9
Gas Combined-Cycle	9,241	$ 1,100		$ 44	$ 16	55%	25	$ 120.06	$ 10,165	10
Gas Simple Cycle	11,085	$ 900		$ 36	$ 16	38%	25	$ 392.25	$ 9,977	10
TOTAL INVESTMENT COSTS								**$ 34,928**	(million $)	
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE								**$ 123.02**	per MWh	
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE								**$ 9,962**	(million $)	
CO_2 EMISSIONS FROM GAS-FIRED GENERATION ABOVE AT				55.8	te/TJ consumed (IPCC Tier 1 value)			24.32	million tonnes	
TOTAL INVESTMENT COSTS								¥ 2,969	(billion Yen)	
WEIGHTED AVERAGE COSTS OF ELECTRICITY OUTPUT FOR ALL CAPACITY ABOVE								¥ 10.46	per kWh	
TOTAL ANNUAL COSTS FOR ALL CAPACITY ABOVE								¥ 847	(billion Yen)	
COSTS CONVERTED TO YEN AT			85	Yen per dollar (4-5-2011 value, and also near average for past year)						

Difference in annuallized costs between EE/RE/DG and Central Power Station alternatives: $ 1,021 million dollars, or $ 86.77 billion yen, or 9.3%

Consideration of value of userved load:
If unserved load is worth $8.80 per kWh (similar to value from German study in note 12), then this difference is decreased to zero if the EE/RE/DG case results in 116 GWh less of unserved load then the central power station case. As this is only 0.2% of the annual year-four output of the EE/DG package, even considering a ramp-in period for the EE/RE/DG package, this quantity of represents only a few weeks worth of the 2 -3 years of energy that the EE/DG/RE package would provide before the resources in the central power station option became available.

Notes and Sources:

1. Costs in the literature for fuel cell power systems vary widely. A report prepared for the US Department of Energy http://www.netl.doe.gov/technologies/coalpower/fuelcells/publications/Natural%20Gas%20DG%20FC%20paper%20update%20090330a.pdf quotes costs for large (5 MW) systems at under $1000 per kW for Solid Oxide Fuel Cells using natural gas at an efficiency of 57%. Other references put the cost of commercial fuel cell units at over $10,000 per kW. We use an intermediate figure, though the cost shown could drop rapidly as the technology is widely deployed.

2. Small generators are widely available from many sources. Japanese brands tend to be much more expensive than other brands (such as imports from China), and we are not sure what the average installation costs for a fixed installation of a small generator unit would be. The capital cost shown can be considered an higher-end. average between domestic Japanese and imported units.

3. Rough estimate based on values in literature. Capital cost shown is between costs for internal combustion and micro-turbine units of approximately 300 kW capacity, both fueled with natural gas.

4. Photovoltaic costs for non-Japan systems slightly less than the costs quoted in Rocky Mountain http://www.rmi.org/Content/Files/BOSReport.pdf, "Achieving Low-Cost Solar PV: Industry Workshop Recommendations for Near-Term Balance of System Cost Reductions", dated September 2010, prepared by Lionel Bony, Stephen Doig, Chris Hart, Eric Maurer, and Sam Newman. The capital cost shown is slightly lower than the average cost quoted in the study (which is for grid-connected, commercial-sized systems), and is before taking account of most of the "balance of system" cost reductions described in the report.

5. PV costs in Japan are assumed to be somewhat higher than in the US, as described, for example, in the Lawrence Berkeley National Laboratory Study Tracking the Sun III: The Installed Cost of Photovoltaics in the United States from 1998-2009, by Galen Barbose, Naïm Darghouth, and Ryan Wiser, dated December, 2010, and available as http://eetd.lbl.gov/ea/emp/reports/lbnl-4121e-ppt.pdf, which quotes $6/kW for residential systems, though in fact, for installations of similar scale, Japanese costs may be similar to those in the US. IF solar PV modules or systems are imported from China, costs are likely to be lower still.

6. Rough estimates, based on several sources. After falling unit the early 2000s, wind power capital costs generally increased prior to the 2009 global economic downturn, in part due to higher prices for metals and other commodities in the world markets. Since that time, capital costs have begun to fall again somewhat.

7. Recent LNG spot prices in Japan as of February 2011 were in the range of $12 per GJ (see, for example, http://www.mongabay.com/images/commodities/charts/chart-lng.html Mongabay.com, "Natural gas LNG, Japan price chart"). Another source quotes costs of about $10.5 per GJ for gas delivered in December 2010 (LNG World News, "Japan: December LNG Import Costs Up 3.9%", dated 1-31-2011, and available as http://www.lngworldnews.com/japan-december-lng-import-costs-up-3-9/). Future prices for LNG may rise as a result of increased demand in Japan following the earthquake, coupled with a shortage of LNG tanker vessels (see, for example, LNG World News, "LNG Shipping Rates Seen Going Up 67 percent after Japan Quake", dated 3-31-2011, and available as http://www.lngworldnews.com/lng-shipping-rates-seen-going-up-67-percent-after-japan-quake/). For the analysis of costs of gas-fired distributed generation and gas-fired central-station generation, we assume that average LNG import costs

8. It is very difficult to determine the costs of nuclear power in Japan, and even more difficult to determine what those costs will be. A January 2011 news article suggests that TEPCO's contract with two key suppliers for unit 2 of the Higashidori nuclear plant was to cost about $2000 per kW of capacity, but it was unclear from the news article (Tsuyoshi Inajima and Michio Nakayama, "Hitachi, Toshiba May Win 200 Billion-Yen Nuclear Plant Order", Bloomberg, dated 1-26-2011, and available as http://www.bloomberg.com/news/print/2011-01-27/hitachi-toshiba-may-win-200-billion-yen-tokyo-electric-nuclear-contracts.html) whether this outlay accounted for the full capital costs of the plant (which we consider unlikely) and/or whether it included costs for financing the plant (even more unlikely).
Recent estimates for construction costs for reactors in the United states, including financing costs, have run as high as $7000 per kW and more (for example, in Florida). We use $6000/kW as a rough estimate for this comparison, though this cost could be lower--or much higher. Note that the nuclear costs shown here do not include outlays for spent fuel management. Spent fuel management is almost certain to become an increasingly important, and possibly expensive, issue in Japan.

9. O&M and fuel costs for nuclear plants estimated based on estimates for plants proposed by US utilities in Florida. Japanese costs could easily be higher.

10. Capital and O&M costs (fixed O&M cost shown includes variable costs) for gas-fired power plants, as well as plant efficiency figures, are adopted from IEA OECD ENERGY TECHNOLOGY SYSTEM ANALYSIS PROGRAM, Technology Brief E02 – September 2009, "Gas-fired Power", available as http://www.etsap.org/E-techDS/EB/EB_E02_Gas_fired%20power_gs-gct.pdf.

11. Assumes that nuclear power provides 20% of the energy (and equivalent baseload power) provided by the EE/RE/DG package, with combined-cycle gas plants providing 75% of the EE/RE/DG package baseload equivalent power. Simple-cycle gas turbines provide the remaining 5% of energy, and also provide the remaining summer peak capacity provided by the EE/RE/DG package, totalling 10,341 MW.

12. In his presentation "The price of supply security of electrical energy against terrorism", prepared for Energy, Policies and Technologies for Sustainable Economies, 10th IAEE European Conference, Vienna, dated 10-09-2009, and available as http://www.aaee.at/2009-IAEE/uploads/presentations_iaee09/Pr_22_Praktiknjo_Aaron.pdf, Aaron Praktiknjo estimates a value of lost load for for Germany of 6.12 Euros/kWh (2007 Euros) or about $8.8 USD (2010 dollars), based on loss-of-load studies in several other nations.